Faculty of Electrical Technology and Engineering

DEVELOPMENT OF AN EXOSKELETON ARM BASED ON SURFACE ELECTROMYOGRAPHY (EMG) SENSOR

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Bachelor of Electrical Engineering Technology (Industrial Automation & Robotics) with Honours

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DEVELOPMENT OF AN EXOSKELETON ARM BASED ON SURFACE ELECTROMYOGRAPHY (EMG) SENSOR

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Tarikh: 12/01/2024

DECLARATION

I declare that this project report entitled "DEVELOPMENT OF AN EXOSKELETON ARM BASED ON SURFACE ELECTROMYOGRAPHY (EMG) SENSOR" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology (Industrial Automation & Robotics) with Honours.)

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Date : 12/01/2024

DEDICATION

I want to thank my parents, Mohd Azam bin Abu Hassan and Nurhuda binti Mohammad, for their unwavering love, support, encouragement, and sacrifices that have formed my life. I would not have gotten this far without their tireless effort. My deepest gratitude also goes to my siblings, who have always led and inspired me, offering moral, spiritual, emotional, and material support. I am also grateful to my colleagues who helped me through this difficult semester and contributed to the project's success.

ABSTRACT

In recent years, there has been a significant amount of research dedicated to the development of robotic exoskeleton systems. These technologies have been widely explored for their potential in virtual reality, human power enhancement, robotic rehabilitation, human power assist, and haptic interface applications. This particular project focuses on creating an exoskeleton arm that can assist individuals in carrying heavy objects. This exoskeleton arm is initially designed using Fusion 360, with the identification and calculation of important components such as the exoskeleton structure, motors serving as joints, an electromyography (EMG) sensor, and an Arduino Uno microcontroller. The project involves various aspects of mechanical design, electronic components, and programming. The effectiveness of the developed exoskeleton arm is then tested through experiments involving several individuals lifting a 2.5 kg and 5.0kg load. The results of the experiments demonstrate that the force generated by the muscles is reduced when using the exoskeleton arm, compared to using a supporting system. Individuals' performance dropped by 36.06% to 50.44% when using an exoskeleton to lift 2.5 kg. This emphasises its effect on muscle activation and efficiency following physical activity. A 10.14% to 23.25% decline in a 5.0 kg lift shows nuanced impacts, emphasising the need for personalised modifications.

ABSTRAK

Sejak beberapa tahun kebelakangan ini, banyak penyelidikan telah dilakukan bagi penciptaan sistem eksoskeleton robotik. Teknologi ini telah banyak diuji untuk potensinya dalam aplikasi realiti maya, peningkatan kuasa manusia, rehabilitasi robotik, bantuan kuasa manusia, dan antara muka haptik. Projek khusus ini memberi tumpuan kepada pembangunan lengan eksoskeleton yang dapat membantu individu mengangkat objek berat. Eksoskeleton Lengan ini pada peringkat mula direka menggunakan Fusion 360, dengan pengenalan dan pengiraan komponen penting seperti struktur eksoskeleton, motor yang berfungsi sebagai sendi, sensor elektromiografi (EMG), dan mikropengawal Arduino Uno. Projek ini melibatkan pelbagai aspek reka bentuk mekanikal, komponen elektronik, dan pemrograman. Keberkesanan lengan eksoskeleton yang dibangunkan kemudian diuji melalui eksperimen yang melibatkan beberapa individu mengangkat beban 2.5kg dan 5.0kg. Hasil eksperimen menunjukkan bahawa daya yang dihasilkan oleh otot berkurangan apabila menggunakan lengan eksoskeleton, berbanding dengan menggunakan sistem sokongan. Prestasi individu menurun sebanyak 36.06% kepada 50.44% apabila menggunakan exoskeleton untuk mengangkat 2.5 kg. Ini memaparkan kesannya terhadap pengaktifan dan kecekapan otot berikutan aktiviti fizikal. Penurunan 10.14% hingga 23.25% dalam lif 5.0 kg menunjukkan kesan bernuansa, menekankan keperluan untuk pengubahsuaian yang diperibadikan.

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CHAPTER 1

INTRODUCTION

1.1 Background

The development of Arm Exoskeleton has been primarily aimed at reducing the mechanical load on the shoulder and redistributing the weight of the arms. The novel technology exhibits potential in mitigating musculoskeletal disorders (MSDs) that frequently emanate from muscular exhaustion and repetitive strain. Arm Exoskeleton endeavours to reduce the prevalence of work-related injuries and improve occupational health by offering external support and assistance to address the risk factors associated with MSDs[1]. Musculoskeletal disorders (MSDs) are a prevalent source of pain and discomfort among individuals in the workforce, impacting various components of the musculoskeletal system such as muscles, bones, spinal discs, tendons, joints, ligaments, cartilage, nerves, and blood vessels[2]. MSDs are highly prevalent among healthcare professionals, with reported rates exceeding 80% among physiotherapists, masseurs, nurses, midwives, dentists, and surgeons, thereby indicating a significant risk for this population[3].

The Electromyography (EMG) sensors has been established in gauging muscle activation levels and approximating joint angles, thereby furnishing crucial feedback for regulating exoskeleton apparatus. The research utilised a personalised calibration methodology to discern the user's intention to either lift or release a load while operating an upper-limb exoskeleton. The process of calibration entailed the utilisation of a cost-effective electromyography (EMG) sensor bracelet, which was strategically positioned around the user's arm. The EMG sensor bracelet facilitated the recognition and analysis of the user's intended movements and actions by detecting the electrical signals produced by the muscles. The amalgamation of individualised calibration methodologies with inexpensive EMG sensors presents a hopeful strategy for attaining improved regulation and efficacy in exoskeleton frameworks[4].

Arm exoskeletons have exhibited their effectiveness in reducing the mechanical burden placed on the shoulder while performing tasks that require overhead work. Arm exoskeletons have been designed with innovative features and functionality that effectively reduce the burden on the shoulder joint by providing external support and assistance. The decrease in mechanical burden holds noteworthy importance in occupational environments where there is a prevalence of overhead work. This decrease aids in the mitigation of musculoskeletal disorders (MSDs) that are linked to extended and repetitive overhead motions. The implementation of Arm exoskeletons in such settings exhibits significant potential for augmenting occupational well-being and mitigating the prevalence of work-related harm[5].

1.2 Problem Statement

This project aims to address the following problems faced by researchers and developers of Exoskeletons:

People who engage in physically demanding industries have a long-term prevalence of Musculoskeletal diseases (MSDs), which refer to a set of medical illnesses affecting the muscles, joints, tendons, ligaments, nerves, and other soft tissues of the body. These problems can cause pain, stiffness, and reduced range of motion, limiting a person's ability to do daily tasks. Furthermore, the exoskeleton arm is intended to solve the restrictions and obstacles that workers have when executing physically demanding activities, which can result in tiredness, injury, and decreased productivity. The exoskeleton arm is designed to support and aid the user, minimising strain on the body and boosting overall labour efficiency. Finally, the primary obstacles hindering the utilisation of exoskeleton arm technology in human labour are the significant expenses and performance constraints associated with the existing systems.

1.3 Project Objective

The main objectives of this project:

a) To design and build a working prototype of an elbow joint exoskeleton arm prototype.

b) To integrate EMG sensor to the exoskeleton arm prototype to provide real-time feedback, force, and movement.

c) To evaluate performance and effectiveness of elbow joint exoskeleton arm.

1.4 Scope of Project

The scope of this project are as follows:

To develop an exoskeleton arm that produces assistive force for use in rehabilitation and to aid users with daily activities such as lifting heavy objects. The power assist exoskeleton proposed in this work is controlled by EMG inputs from the muscles. The study's participants will receive instructions to perform a lifting task with a standardised 2.5 kg load while utilising the exoskeleton arm. The measurement of the force exerted by the participants' muscles during the task will be conducted through the utilisation of force sensors that have been integrated into the exoskeleton arm.

In order to conduct a comparative analysis, the user will undertake the identical lifting task in without of the exoskeleton arm. The muscular force generated by the individuals involved in this particular situation will also be quantified for comparative purposes. The data collected, encompassing the muscular force generated during the utilisation of the exoskeleton arm and the force applied in the absence of the exoskeleton arm, will be subjected to rigorous analysis. The application of statistical methods will be utilised to quantify the extent of reduction in muscle force resulting from the assistance rendered by the exoskeleton arm. The forthcoming analysis will entail a comparison of the muscle forces obtained from the two conditions, followed by the identification of any statistically significant disparities.

The study intends to give quantitative evidence of the exoskeleton arm's efficiency in lowering muscle force during lifting tasks by thoroughly analysing the obtained data. These findings will help researchers better understand how the exoskeleton arm can reduce physical strain and improve the user's capacity to handle heavy goods.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Exoskeleton Technology

In 1890, N. introduced a groundbreaking conceptual model for a robotic exoskeleton, which received a US Patent upon completion. This innovative device, designed as a lower extremity enhancer, consisted of a parallel-operating lengthy bow that could potentially assist individuals in various activities such as walking, running, and jumping. The development of exoskeleton technology continued to evolve over the years, with notable advancements exemplified by the creation of the Hardiman I Exoskeleton in 1965. Spearheaded by the General Electric Company in collaboration with the Army and Navy, the Hardiman exoskeleton emerged as a fully powered device, featuring an impressive 30 degrees of freedom and weighing approximately 680 kilograms (1500 pounds)[6], [7]. The growing recognition of exoskeletons and their multifaceted applications in the military and rehabilitation sectors has attracted researchers to explore and innovate new technologies. Particularly in military contexts, exoskeletons play a pivotal role in enhancing soldiers' physical strength and endurance, enabling them to carry heavy loads for extended periods and navigate diverse terrains with reduced metabolic costs. As a result, these advancements not only minimize fatigue among soldiers but also enhance their overall agility[6].

2.1.1 Different types of exoskeletons

Two primary categories of exoskeletons have been devised to augment human abilities and physiological aptitude: exoskeletons for the upper body and exoskeletons for the lower body. The various exoskeleton variations are tailored to specific goals and incorporate distinct design elements to meet the needs of the user. Upper limb exoskeletons are designed to enhance the strength and endurance of the arms and shoulders, while lower limb exoskeletons are intended to augment the lower extremities, including the legs and hips. The utilization of advanced engineering and robotics has positioned exoskeleton technologies to potentially revolutionize various industries, including healthcare, manufacturing, and defense. The overarching objective is to enhance the capacity of individuals, foster workplace safety, and implement revolutionary functionalities that surpass traditional bodily constraints.

2.1.1.1 Upper body exoskeletons

The notion of upper limb exoskeletons that can be worn is based on the complex anatomy of the human arm, which includes the shoulder complex, elbow complex, and wrist complex. The shoulder complex is composed of three bones, namely the clavicle, scapula, and humerus, and four articulations, including the glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic joints. The thorax serves as a structural foundation for this complex. The glenohumeral joint, also referred to as the shoulder joint, operates as a ball and socket joint that establishes a connection between the humerus and scapula. This articulation exhibits a total of five independent degrees of motion, comprising of three rotational and two translational degrees of freedom. In contrast, the elbow complex exhibits a predominant degree of freedom, whereas the wrist complex is comprised of three degrees of freedom. The upper limb exhibits a broad spectrum of motion and flexibility due to the allowance of movement in both positive and negative directions for each degree of freedom.[8]. Figure 2:1 show human upper limb motions:

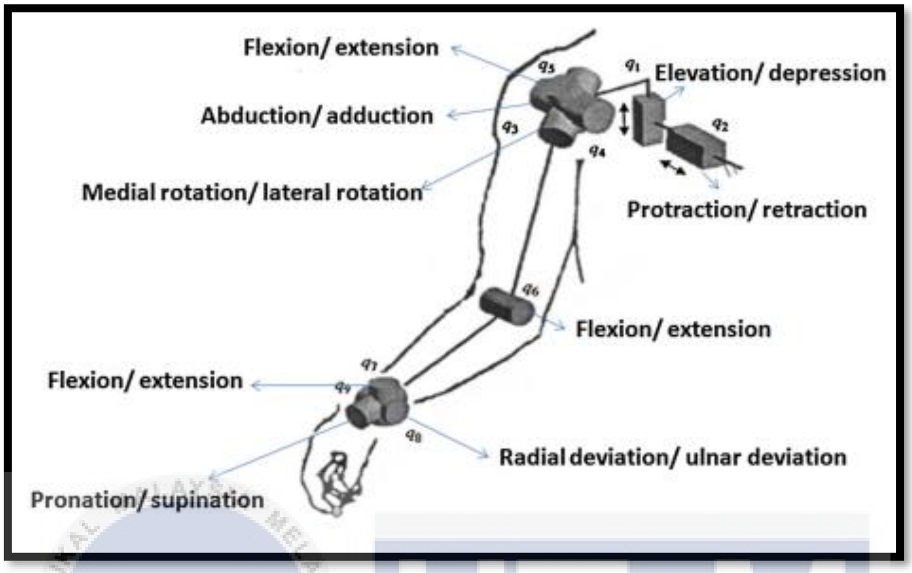

Figure 2.1 Human upper limb motions

Ensuring the safety of upper-limb exoskeleton robots that have direct interaction with human users is of utmost significance. As a result, there has been a development of upper-limb exoskeleton robots that cater to various fundamental needs. An exoskeleton robot that is tailored to aid in wrist motion has successfully addressed the issue of axis deviations linked to wrist flexion/extension and wrist radial/ulnar movement. Through a thorough examination of these variables, the exoskeleton robot guarantees precise and regulated assistance for the user's wrist articulations. The aforementioned accomplishment highlights the importance of fulfilling essential design factors in order to improve the efficacy, security, and general user satisfaction of upper-extremity exoskeleton robots[9].

In the design of upper-limb exoskeleton robots, careful consideration must be given to the movement of the center of rotation of the shoulder joint in accordance with the motions of the upper arm. This is crucial to mitigate any negative effects that may arise from this misalignment. When the exoskeleton needs to be attached to both the forearm and upper arm of the user to assist both upper-arm and forearm motions, it becomes necessary for the upper-limb exoskeleton robot to incorporate a mechanism that enables the movement of the center of rotation of the shoulder joint.

This adjustment is essential to effectively assist the upper-arm motions of the user. By implementing this technique, it is believed that the negative effects caused by the positional disparity between the center of rotation of the human shoulder and that of the robot shoulder can be minimized. Additionally, it is imperative to ensure that the robot's working space is designed to avoid the occurrence of mechanical singularities, where the robot's movements become limited or unpredictable[10].

2.1.1.2 Lower body exoskeletons

Lower body exoskeletons were created with the primary goal of assisting and supporting the lower back region. Among the described forms, passive industrial exoskeletons have been specifically created to relieve strain and limit stress on the lower back area. These exoskeletons have proven to be quite effective in both dynamic lifting and static holding duties. Active exoskeletons, on the other hand, have even greater potential for lowering physical demands. The use of active exoskeletons has resulted in significant load reductions, which can be beneficial for a variety of body regions, including the lower body, trunk, and upper body. Active lower body exoskeletons can contribute to greater ergonomic support and perhaps improve occupational performance in a range of scenarios by reducing the physical stress placed on these areas[11].

The exoskeleton's degree of freedom (DOF) was precisely aligned with the DOF of human lower limbs, taking into account anatomical aspects of the lower limb. In a general sense, the human lower extremities can be thought of as having seven degrees of freedom. The lower limb, in particular, has seven rotational degrees of freedom, three at the hip joint, one at the knee joint, and three at the ankle joint. The basic locomotive activities mostly include hip, knee, and ankle joint flexion and extension. In accordance with this knowledge, the exoskeleton was purposely constructed with a flexion and extension knee joint, as well as an ankle joint capable of flexion and extension, abduction, and adduction. These design considerations intended to optimize the exoskeleton's overall mechanical structure, assuring alignment with the natural movements of the human lower extremities[12].

Human lower limbs are made up of three primary joints: the hip joint, the knee joint, and the ankle joint. Each of these joints is critical in allowing mobility and sustaining the body's weight. The hip and ankle joints each have three degrees of flexibility, allowing for a variety of rotational movements. The knee joint, on the other hand, is a more complex joint, and for the purposes of this study, a simplified analysis with a single degree of freedom is used, which is consistent with the method used by many commercially available exoskeleton systems. In terms of underlying anatomical structures, the femur is the primary bone involved in hip and knee joint articulation, while the tibia and fibula are the primary bones involved in knee and ankle joint articulation. The bones located below the tarsal joint are referred to collectively as the foot bones. The femur, tibia, fibula, and foot bones not only support the body's weight but also contribute to total structural connectedness, allowing coordinated movement and mobility[13]. Figure 2:2 show bones, joints and muscle diagram of human lower limbs:

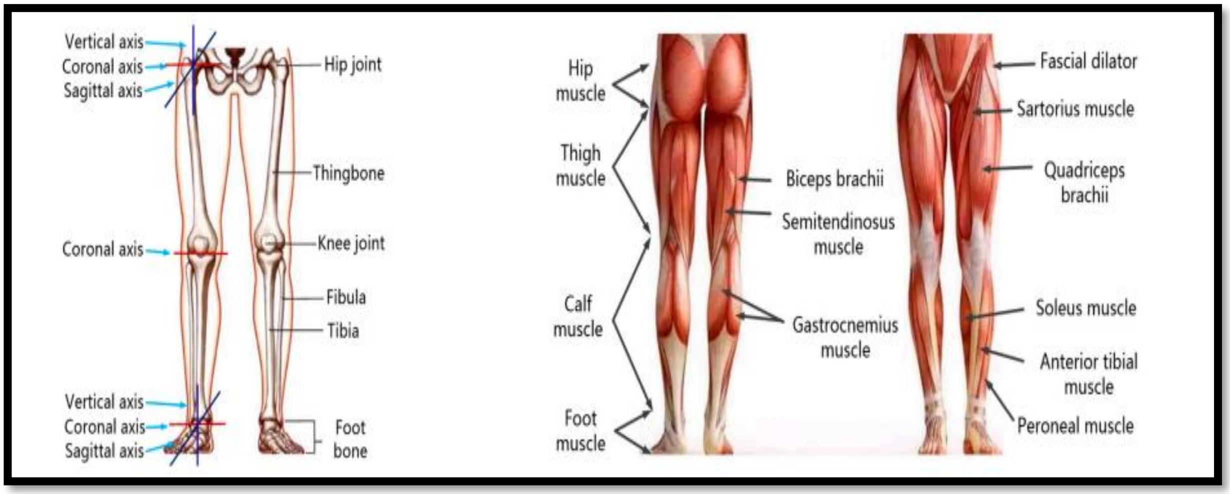

Figure 2.2 Bones, joints and muscle diagram of human lower limbs

The degree of expansion and contraction of skeletal muscles in the lower limbs and the subsequent torque exerted on the joints are easily visible. The coordinated movement of skeletal muscles, through expansion and contraction, allows joints to rotate. This mechanism is required for executing motions in the lower limbs, allowing for a variety of locomotive tasks to be performed. The torque generated within the joints allows for controlled and coordinated motions by adjusting the contraction and relaxation of certain muscle groups, adding to the general functionality and mobility of the lower limbs[13].

Table 2:1 Comparision between upper body exoskeleton and lower body exoskeleton:

Feature	Upper Body Exoskeletons	Lower Body Exoskeletons
Targeted Body Area	Shoulders, arms, and upper torso	Hips, thighs, and lower limbs
Complexity of Anatomy	Complex anatomy with multiple degrees of freedom in shoulder, elbow, and wrist joints	Relatively simpler anatomy with fewer degrees of freedom in hip, knee, and ankle joints
Typical Applications	Heavy lifting, overhead work	Walking, running, standing, load-bearing tasks
Safety Considerations	Center of rotation alignment and avoiding mechanical singularities	Alignment with lower limb anatomical aspects
Power Source	Electric-powered or pneumatic	Electric-powered or hydraulic
Degree of Mobility	Limited mobility and range of motion	Enhanced mobility and range of motion
Weight Distribution	Concentrated on upper body	Distributed across lower body
Supportive Mechanisms	Exoskeleton arms, gloves, or vests	Exoskeleton legs, braces, or suits
Fatigue Reduction	Reduces upper body fatigue	Reduces lower body fatigue
Rehabilitation Potential	Assists in upper body rehabilitation	Assists in lower body rehabilitation
Ergonomic Support	Aids wrist motion and ensures proper axis alignment	Supports lower back region and reduces physical stress on lower body, trunk, and upper body

2.1.2 Applications and benefits of exoskeletons in various fields

Exoskeletons, also known as wearable robots, possess a diverse array of applications and advantages across multiple domains. The wearable devices offer supplementary assistance and amplification to the individual's physique, thereby improving their physical power, movement, and stamina. Exoskeletons are utilized in healthcare settings to facilitate rehabilitation and physical therapy, whereas in industrial settings, they serve to enhance worker safety and productivity. Furthermore, these technologies have practical uses in the fields of military, aerospace, sports, and geriatric care. Exoskeletons offer a range of advantages such as heightened physical abilities, lowered susceptibility to injuries, improved rehabilitation results, heightened efficiency, and broadened opportunities for individuals with limited mobility. Exoskeletons are revolutionizing various sectors and enhancing the standard of living owing to their adaptability and potential.

2.1.2.1 Exoskeletons in teleoperation.

The Exoskeleton system operated as a teleoperation system employing a master-slave configuration, wherein a remote arm was controlled through an input device. The proposed system comprised a telerobot with dual arms capable of manipulating various objects with human-like dexterity. The remote control was carried out by a human operator utilizing a harness equipped with exoskeleton-like sleeves and gloves. The telerobot's remote manipulator accurately tracked the arm, hand, and finger movements of the operator and provided either force feedback or positional data. This enabled the operator to experience a sense of manipulating the object held by the telerobot. The manual dexterity of the hand was facilitated by the activation of tendons using actuators and controllers located in the forearm, which was attached to a commercially available PUMA 560 manipulator. The development of this exoskeleton project, supported financially by the NASA Office of Aeronautics and Space Technology, reached its culmination on September 4th, 1991[14]. Figure 2:3 show exoskeleton Anthropomorphic Slave Arm (circa 1991) and Exoskeleton Telemanipulation, 1994 source: NASA JPL

Figure 2.3 Exoskeleton Anthropomorphic Slave Arm (circa 1991) and Exoskeleton Telemanipulation, 1994 source: NASA JPL

2.1.2.2 Exoskeleton in Sports Rehabilitation

End effectors, suspension, and an exoskeleton robot comprise the system configuration specifically developed for upper extremity rehabilitation. Exoskeleton robots, as opposed to end effectors and suspension, have the advantage of allowing independent joint mobility, allowing for accurate replication of rehabilitation activities over a spectrum of motions. The active rehabilitation training modality includes approaches to single-joint and multi-joint compound training. The capabilities of the exoskeleton robot substantially influence the efficiency of rehabilitation training. During the early stages of physical rehabilitation training, the exoskeleton robot supports patients in performing certain actions through programmed direction. Using a human motion capture device, the therapist assists the patient in repeating the training activities. Following that, the system breaks down the training activity to calculate the trajectory and parameters like joint angle and angular velocity. To achieve seamless transitions, the exoskeleton joints' angular velocity and angular acceleration are governed by the five-pass polynomial interpolation approach. Throughout the training process, continuous feedback systems are used to maintain patient safety[15]. Figure 2:4 shown example exoskeleton in sports rehabilitation:

Figure 2.4 Exoskeleton in Sports Rehabilitation

2.1.2.3 Exoskeleten in Military

The primary objective of exoskeletons developed for military use is to minimize soldier fatigue and the likelihood of injury. Typically, they are not designed for direct combat applications. Instead, they are intended for use by soldiers who are embarking on lengthy journeys and need to traverse a significant distance within a limited timeframe. Reducing soldier fatigue is a logical priority given the demanding tasks that soldiers are required to perform. Each soldier is required to carry equipment weighing between 100 to 150 pounds, which may need to be transported over long distances, often through challenging and uneven landscapes. Moreover, soldiers should be equipped to perform tasks such as jumping from elevated locations, safely landing after parachuting, or transporting an injured comrade weighing several hundred pounds to a secure location. The physical exertion of carrying heavy equipment puts a significant amount of pressure on the legs and joints. This can lead to fatigue and strain, resulting in a decrease in the amount of time a soldier can remain active each day. Additionally, this increases the likelihood of developing chronic injuries. Exoskeleton implementation can potentially address this issue. Studies have demonstrated that utilizing an exoskeleton suit to aid with everyday activities can decrease the probability of a soldier developing long-term injuries[16]. Figure 2:5 show exoskeleton in Military:

Figure 2.5 Exoskeleton in Military

2.2 Electromyography (EMG) Sensors and Muscle Signal Analysis

Electromyography (EMG) sensors are widely used to detect and analyse muscle activity in a variety of settings, including clinical settings, rehabilitation, sports science, and biomechanics research. The electrical potentials generated by muscle cells in response to neurological or electrical inputs are captured by these sensors. EMG signals can provide useful information regarding muscle functionality, performance, recruitment order, and the existence of medical abnormalities.

2.2.1 Introduction to electromyography (EMG) sensors and their principles

Electromyography (EMG) is a sensor that detects muscle action and the passage of nerve fibers within them. EMG is used in clinical settings to identify damaged muscles and nerves, explore the underlying causes of muscular dysfunction, monitor the healing process after motor nerve injuries, and watch nerve regeneration. EMG data is also used to improve the content of muscle training workout apps that are offered to customers. This information can be used to calculate the Muscle Quality Index (MQI), which provides information about muscle functionality and performance. The electrical potential generated by muscle cells in response to electrical or neurological stimulus is detected by EMG. These signals can be used to investigate the biomechanics of human body movement, detect medical anomalies, quantify muscle activation levels, and examine recruitment order. Furthermore, EMG signals can be used to detect a variety of medical anomalies. The amplitude of the EMG potential can vary greatly, ranging from 50 V to 30 mV, depending on factors such as the specific muscle being studied and the conditions present during the observation.[17].

2.2.2 Signal acquisition techniques and considerations

Following the recognition of movement by the EMG sensor, it generates an analog signal. This signal then undergoes the process of signal conditioning, which involves amplification and filtering, to improve its quality and remove unwanted noise. Subsequently, the conditioned analog signal is converted into digital data using an analog-to-digital converter (ADC). In order to obtain meaningful muscle signals for rehabilitation purposes, an electromyogram (EMG) circuit is implemented. The EMG signal acquisition system for clinical rehabilitation comprises several components, including the instrumentation amplifier, which amplifies the weak EMG signals, filtering components to remove unwanted frequencies, a rectifier to convert the AC signal to DC, an ADC to convert the analog signal to digital form, a microcontroller to process and analyze the digital data, and a display unit to present the results to the user or clinician. Together, these components form a comprehensive EMG signal acquisition system that enables the monitoring and analysis of muscle activity for effective clinical rehabilitation purposes[18]. Figure 2 6 shows the general block diagram of the whole system. Figure 2:6 shows the general block diagram of the whole system:

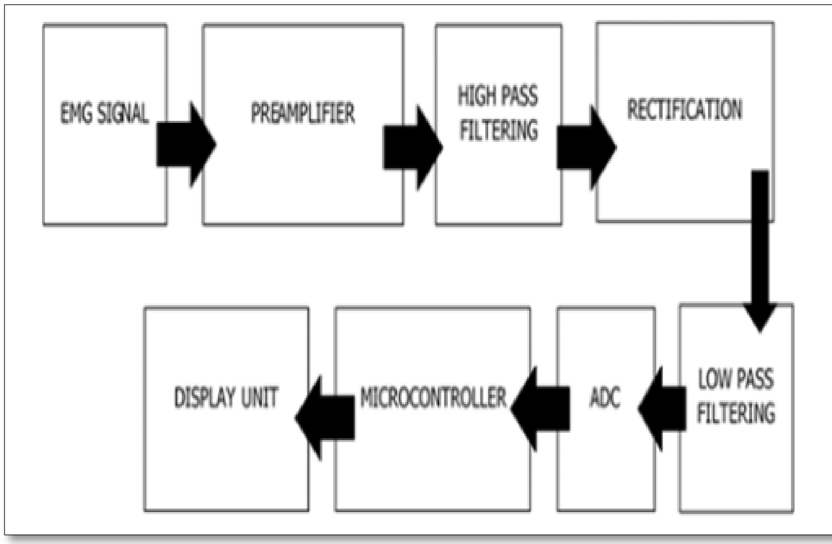

Figure 2.6 the general block diagram of the whole system[18]

2.2.2.1 Preamplifier

The circuit depicted in Figure acts as an instrumentation amplifier and a pre-amplifier developed specifically to record Electromyography (EMG) signals originating from muscles using non-invasive electrodes. Two operational amplifiers (op-amps) are used in this circuit to amplify the voltage difference between two electrodes to a desirable level for subsequent processing. Equation 1 can be used to calculate the overall gain of the instrumentation amplifier, allowing the amplification factor required to achieve the desired signal amplification to be determined[18]. Figure 2:11 show Two Op-Amp Instrumentation Amplifier:

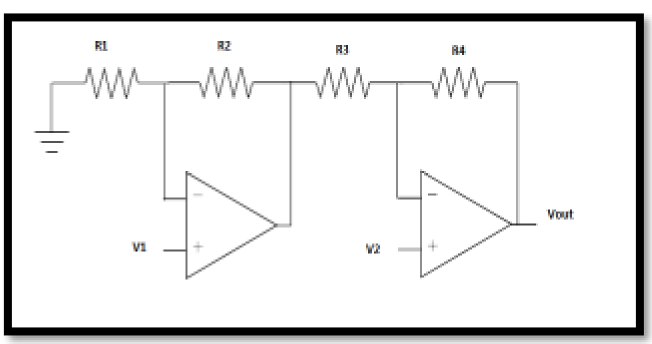

Figure 2.7 Two Op-Amp Instrumentation Amplifier[18]

2.2.2.2 High Pass Filter

An active high-pass filter is used in the circuit to handle the presence of unwanted noise and offset voltage in the recorded EMG signal. This addition is intended to eliminate the DC offset and reduce noise interference. The offset voltage is often created by the circuit's DC supply, and the noise associated with it might impair later signal analysis and processing. The high-pass filter permits only high-frequency components of the EMG signal to pass through while attenuating or blocking low-frequency components by selecting a cutoff frequency in the range of 0 Hz to 10 Hz. This efficiently reduces offset-related noise from the signal and improves its overall quality for future analysis and processing[18].

2.2.2.3 Rectification

In the circuit, a precision rectifier is used instead of a normal rectifier. This option is chosen to address the problem of the 0.7V forward bias voltage drop that happens with a standard rectifier, which alters the EMG signal across the diode. The EMG signal normally swings between positive and negative values during muscle movement. A full-wave rectifier is utilized instead of a half-wave rectifier to ensure precise signal representation. The rectifier can thus catch both the positive and negative values of the EMG signal generated by muscular activity. The information contained in both the positive and negative regions of the EMG signal is preserved by using a full-wave rectifier, reducing the chance of losing crucial input data. Following rectification, signal smoothing techniques can be used to improve signal quality even more[18].

2.2.2.4 Low Pass Filter

The microprocessor computes the average of the input signal to provide signal smoothing of the EMG signal. An active low-pass filter is used in this process. A low-pass filter is a type of electronic circuit that enables low-frequency signals to pass while suppressing high-frequency signals. The variations in the EMG signal can be efficiently decreased by using a low-pass filter. This filtering technique aids in the removal of high-frequency noise and undesirable changes in the signal, resulting in a more smooth depiction of the underlying EMG activity. In the signal smoothing process, the use of a low-pass filter aids in creating a cleaner and more trustworthy EMG signal for subsequent analysis and interpretation[18].

2.2.3 Types of Electromyography (EMG) sensors

Electromyography (EMG) sensors are crucial in the acquisition and analysis of electrical activity produced by muscle reactions. Surface EMG sensors and intramuscular EMG sensors are the two most popular types of EMG sensors. Surface EMG sensors are implanted on the skin right above the targeted muscle and detect electrical signals released by the superficial muscle fibers. These sensors provide non-invasive measurements and are more comfortable for the user. Intramuscular EMG sensors, on the other hand, include the insertion of small needle electrodes directly into muscle tissue, giving a more thorough and reliable measurement of electrical activity at a deeper level.Intramuscular EMG sensors are typically employed in clinical settings and research studies that require precise measurements. Each type of EMG sensor possesses distinct advantages and limitations, and the choice between them depends on the specific requirements of the application and the desired level of detail in the electrical activity analysis.

2.2.3.1 Surface Electromyography (EMG) snesors

Surface Electromyography (sEMG) has traditionally been linked with collecting muscle activity in the superficial layers of muscles, providing limited information about deeper muscle activation. However, technological developments and the use of multi-channel electrode arrays have made it possible to manipulate inter-electrode distances (IEDs) and monitor muscle activation at different depths. Researchers and physicians can alter the electrode design to target specific muscle groups and probe deeper layers of muscle tissue by modifying the IEDs. This has improved sEMG's capabilities by allowing it to evaluate and analyse the activation patterns of both superficial and deeper muscles, resulting in a more comprehensive understanding of muscle function and performance. These advancements have increased sEMG's versatility and applicability in a variety of sectors, including rehabilitation, sports science, and biomechanics research[19].

Surface electromyography (sEMG) is a useful technique for detecting and monitoring biopotentials generated by muscle fibers in response to neurological or electrochemical stimuli. It gives critical information regarding muscle activation, tone, and exhaustion, as well as patterns of recruitment and synchronization. The use of sEMG allows for the recording of full muscular biopotential signals from several muscle groups, allowing for the assessment of the functional condition of a specific muscular region rather than a single motor unit. The surface technique takes use of the high electrical conductivity on a broader scale, lessening the influence of electrode proximity on the shape and source properties of the signal. This noninvasive method uses electrodes that do not need to be inserted into the muscle, which eliminates the discomfort and potential hazards associated with invasive monitoring procedures. sEMG is a helpful tool in a variety of domains, including rehabilitation, sports science, and clinical assessments, as it provides valuable insights into muscle function and informs diagnostic and therapeutic decisions. [20]. Figure 2:8 show the surface Electromyography (sEMG):

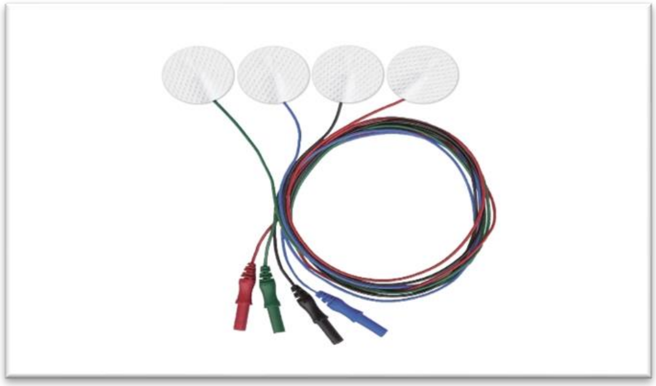

Figure 2.8 Surface Electromyography (sEMG)

Surface Electromyography (sEMG) signals are the sum of electrical potentials associated with muscle contractions. These signals are recorded noninvasively utilizing electrodes inserted on the skin's surface. However, a variety of circumstances might inject contaminants into the signals, affecting their amplitude, temporal properties, and frequency content, which are often employed in control and evaluation applications. The quality of the obtained signals has a significant impact on the reliability and effectiveness of EMG applications. It is critical to carefully locate the sensors on the targeted muscles, firmly attach them, and maintain a generally stable recording environment to ensure reliable data. These conditions can be difficult to achieve, especially during long periods of unmonitored observation involving unskilled users. Noise, interference, and artifacts are more likely to occur in uncontrolled monitoring situations. Furthermore, the expanding volume of data from many sources, along with constant monitoring, makes manual data quality assessment impossible. As a result, automated methods to analyze the quality of EMG signals are required, allowing for more reliable and efficient data analysis and interpretation[21]. Figure 2:9 Sample signals for clean EMG and EMG contaminated with (a) power-line interference, (b) quantization noise, and (c) motion artifact for Surface Electromyography (sEMG):

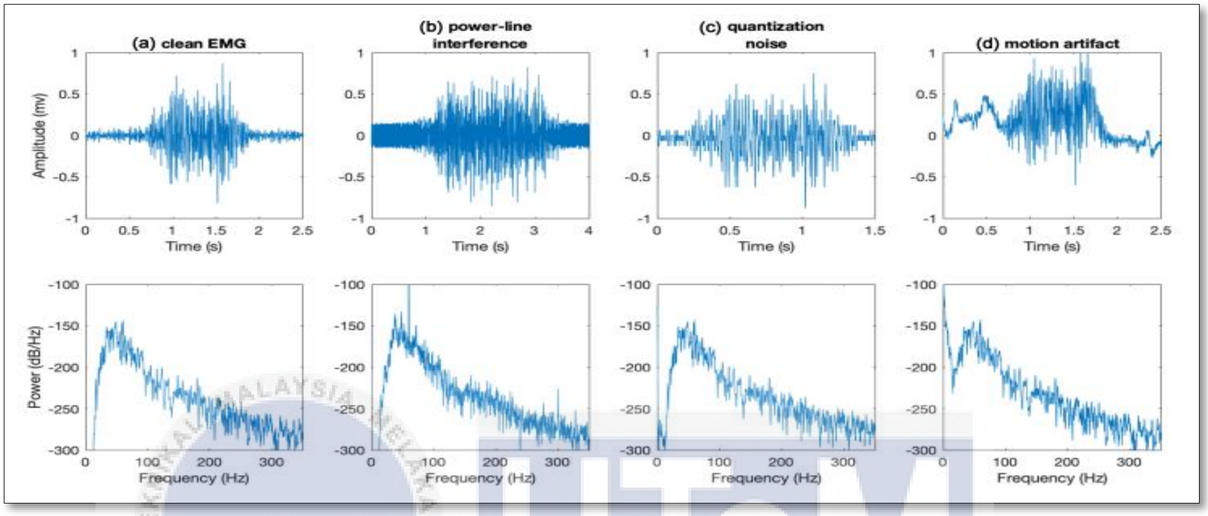

Figure 2.9 Sample signals for clean EMG and EMG contaminated with (a) power-line interference, (b) quantization noise, and (c) motion artifact for Surface Electromyography (sEMG) [21]**.**

The absence of signal contaminants distinguishes clean EMG signals. While synthetic EMG signals can achieve this ideal state, real-world high-quality EMG recordings can only come close. The quality of EMG signals is frequently harmed by noise, interference, and artifacts. Contamination or a bad configuration of the EMG acquisition equipment might cause instrument noise and distortion. To reduce instrumentation noise, the acquisition system's setup and configuration must be carefully considered. Any extraneous signal that becomes mixed with the EMG signal during recording is referred to as interference. Multiple sources of interference can contribute to the occurrence of white Gaussian noise in the EMG signal when paired with other noise and distortions. Measurement artifacts, on the other hand, are caused by problems with the recording of skin-surface EMG signals. Artifacts can be introduced by poor electrode contact caused by electrode lift, skin stretching, cable motion, or changes in electrode-skin impedance. Furthermore, movement during recording might amplify the appearance of artifacts, which can appear occasionally or consistently throughout the recording session. It is critical to identify and treat these types of noise, interference, and artifacts in order to get reliable EMG signals for proper analysis and interpretation.[21].

2.2.3.2 Intramuscular electromyography (iEMG) sensors

In recent years, there has been a surge of interest in the breakdown of intramuscular electromyography (iEMG) signals from academics from a variety of disciplines. Individual motor units within the human nervous system can be observed and analyzed using this method. Motor units, which represent the brain's coordinated activation of muscle fibers, have enormous promise for applications such as prosthetic limb control, performance evaluation in rehabilitation, and neuromuscular condition detection. To capture the action potentials generated by particular motor units, iEMG electrodes with narrow sensing surfaces were initially used. These electrodes have spatial selectivity, allowing them to detect specific motor unit activity. Researchers can acquire significant insights into the functioning of the neuromuscular system and its implications for numerous clinical and technological applications by examining motor unit action potential trains obtained from iEMG signals. [22]. Needles electrodes were gently inserted into the axial myomeres of confined larvae within the microfluidic chip during the experimental setup. The positioning of the needle electrodes as well as the ground electrode was critical for obtaining intramuscular recordings. The researchers relied on measurements of signal properties and the existence of insertional activity during the electrode insertion process to assure correct location. Electromyography (EMG) is a type of clinical electromyography, Insertional activity detection is required to check that the needle has been correctly placed into the muscle. This event acts as a trustworthy indicator that the electrode is properly positioned within the target muscle tissue, allowing for precise intramuscular electrical activity recording. The researchers hoped to accomplish precise electrode placement and dependable intramuscular recordings for their experimental investigations by taking these parameters into account [23]. Figure 2:10show intramuscular electromyography (iEMG) sensors

Figure 2.10 Intramuscular electromyography (iEMG) sensors

The breakdown of intramuscular electromyography (EMG) signals has emerged as a helpful tool for researching the brain regulation of muscles in vivo. This method entails identifying and classifying action potentials generated by individual motor units within the EMG signal's interference pattern. Initially, intramuscular EMG signal decomposition was only used for high-force contractions that exceeded 50% of maximal force. However, advances in this discipline have now made it possible to analyze the neural input from the brain to muscles at various levels of muscular activity with confidence. Researchers have been able to create conceptual models of motor unit control by decoding and analyzing the activity of individual motor units, providing light on the underlying mechanisms of muscle coordination and motor control. Intramuscular EMG signal decomposition has thus provided valuable insights into the complex relationship between the central nervous system and muscle activation, advancing our understanding of motor unit behavior and facilitating advances in motor rehabilitation and neuromuscular disorder diagnostics.[24].

The distinct properties of intramuscular electromyography (iEMG) signals have received less attention than established methods for collecting motor unit and muscle fiber activity that use fine-wire or needle electrodes. This is mostly due to the limits imposed by the case that holds the electronics and transmitter in iEMG devices, as well as the interelectrode distance and implanted recording electrode arrangement. These variables differ dramatically from the configuration utilized in traditional intramuscular recordings. The design and location of iEMG electrodes provide difficulties in getting comparable signal quality and precise information about motor unit activity. As a result, more research and development are needed to solve these constraints and improve the interpretation and use of iEMG signals for applications such as motor control analysis, prosthesis control, and neuromuscular disorder assessment. By overcoming these obstacles, iEMG has the potential to deliver vital insights into the complexities of muscle function while also improving therapeutic results in rehabilitation and diagnostic settings[25].

The EMG signal needs preprocessing to filter out irrelevant data influenced by external factors, physiological traits, and equipment noise. This typically involves using a low-pass filter to remove baseline and primary frequency components, a high-pass filter to eliminate low-frequency noise, and a notch filter to reject power line interference at 50/60 Hz and its harmonics. Careful selection of cutoff frequencies is important to prevent amplitude loss, waveform distortion, decreased peak time, and artifact development. The processed EMG signal is then sent to a data capture device for further analysis, storage, or evaluation. An analog-to-digital converter is used to convert the analog EMG signal into a digital format, enabling computer-based processes and facilitating quantitative analysis of the EMG data[26].

Table 2:2 Comparison table between Surface Electromyography (sEMG) Sensors and Intramuscular Electromyography (iEMG) Sensors

Type of sensor	Surface Electromyography (sEMG) Sensors	Intramuscular Electromyography (iEMG) Sensors
Placement	Placed on the surface of the skin	Inserted directly into the muscle tissue
Signal Acquisition	Non-invasive	Invasive
Sensing Area	Large sensing area	Limited sensing area
Signal Depth	Captures activity from superficial muscles	Can observe individual motor units within the muscle
Motor Unit Analysis	Does not provide detailed information about individual motor units	Provides detailed information about individual motor units
Applications	Control and assessment applications, muscle activation, tone analysis, muscle fatigue analysis, synchronization patterns, muscle recruitment	Prosthetic limb control, rehabilitation performance evaluation, diagnosis of neuromuscular disorders
Comfort	Noninvasive electrodes, comfortable for long-duration use	Invasive procedure, potential discomfort and risks
Signal Quality	Susceptible to noise, interference, and artifacts from various sources	Improved signal quality, reduced interference from external sources
Pre-processing	Filtering and noise removal required	Filtering and noise removal required
Data Acquisition	Can be easily connected to data acquisition systems	Requires specific data acquisition systems for intramuscular signals

2.2.4 Noise reduction and artifact removal techniques

Electromyography (EMG) signals are valuable for understanding muscle function, yet they often face challenges from noise and artifacts. Factors like power line interference, electrode displacement, and physiological processes unrelated to muscle activity contribute to this issue. To ensure accurate analysis, two effective strategies, inspired by electroencephalography (EEG) solutions, are employed. The first focuses on optimizing electrode-skin contact through techniques like skin abrasion and proper fixation, considering factors such as electrode type and configuration. The second emphasizes enhancing signal quality with appropriate electronics, including amplification, analog filters, sampling rate, and A/D conversion. These methods are crucial for reliable EMG interpretation in clinical and research contexts[27].

In electromyography (EMG), assessing biosignal quality post-acquisition is crucial for signal enhancement. This involves detecting and identifying pollutants and artifacts, quantifying their severity, and employing mitigation strategies to preserve essential signal components. The interconnected processes aim to reduce contamination while retaining meaningful information in EMG signals, ensuring accuracy and reliability. Striking a balance is essential, as excessive removal of impurities may lead to the loss of vital signal components. Quantification features aid in categorizing artifacts, contributing to improved signal quality. Ongoing research and development are imperative for advancing EMG technology in clinical, rehabilitative, and human-machine interface applications[27].

2.3 Existing Exoskeleton Arm Designs

An arm exoskeleton is a wearable robotic device that assists and improves the functionality of the human arm. It is specifically developed to help those with limited arm strength or movement by giving them more power and dexterity to do routine tasks. The exoskeleton is worn on the user's arm and uses advanced sensors, motors, and mechanical components to replicate and augment the user's natural arm movements. These exoskeletons have the potential to improve the quality of life for people with physical limitations by assisting them with arm motions and minimising the effort required for them to participate in daily activities.

2.3.1 Background and Significance

Exoskeleton arm technologies have emerged as wearable devices designed to enhance and extend the capabilities of the human arm. Composed of mechanical structures, sensors, and actuators, these devices collaborate to provide support, strength, and assistance to the user's arm. They find applications in diverse industries, including healthcare, rehabilitation, industry, and the military. In healthcare, exoskeleton arm technologies can aid individuals with impaired arm function, such as those with neurological conditions or disabilities, by assisting in movement and rehabilitation exercises. In industrial settings, exoskeleton arms can reduce the physical strain on workers, enhance productivity, and prevent injuries by providing additional strength and support during repetitive or physically demanding tasks. Furthermore, exoskeleton arm technologies have potential military applications, where they can enhance soldiers' endurance, strength, and precision during combat operations or logistical tasks. The field of exoskeleton arm technology continues to evolve, with ongoing research and development efforts focused on improving functionality, comfort, and user experience to broaden their applications and benefits in various domains.

2.3.1.1 Rehabilitation and Assistive Devices

Exoskeleton arm technologies have been shown to be useful in both rehabilitation and augmentation applications. These gadgets aid in the rehabilitation of people who have had back injuries by assisting with muscle development and motor control relearning. Furthermore, they provide vital assistance to people who work in physically demanding industries, such as construction or delivery roles that need regular lifting of large goods. Exoskeleton arm devices are classified as rehabilitation or augmentation equipment, and they serve the demands of patients recovering from damage to their upper limb muscles and biomechanics, as well as healthy people looking for arm support or improved gym exercises in their regular routines. Exoskeletons can be used in place of regular sporting equipment to boost strength and endurance. They are also intended for people who have muscle injuries and need aid with daily duties. Exoskeleton arm technologies' ongoing development holds promise for further improvements in rehabilitation and augmentation, broadening its applications and advantages to a broader variety of users.[28].

Arm exoskeletons provide both passive and active support functions. Active support is activated by the user's desire to execute a movement, follow a trajectory, accomplish a task, or direct the arm's positioning along a certain path, whereas passive support is triggered by the user's intention to retain the arm in a specific position for a predetermined duration. These exoskeleton devices have a variety of functions, including increasing human power to minimize physical strain in healthy humans and acting as haptic and teleoperation devices. Only a small number of devices were considered to capture extra information throughout the selection process, with the most majority being rejected. Prosthetics were also deemed unsuitable due to their anatomical replacement nature, which contrasts with the goal of rehabilitation or assisting in the restoration of function of wounded body parts. Furthermore, because the study's primary focus was on active rehabilitation and assistive device technologies, passive devices were treated similarly to augmentation and haptic devices, with only a handful being examined for extra information.[29].

2.3.1.2 Exoskeletons in industrial

In the industrial sector, employees are frequently exposed to repetitive lifting tasks that pose a considerable risk of chronic back injury. The performance of repetitive lifting tasks in industrial settings may present a notable hazard of enduring spinal injuries for laborers. Such physical strain during work has been linked to a higher likelihood of experiencing lower back pain. To address this issue, the implementation of a low-cost and lightweight exoskeleton in the workplace would yield benefits for the workers, the company, and society as a whole. This technology would result in an improved quality of life for workers by reducing the long-term negative health effects associated with manual labor. Furthermore, it is anticipated that this would result in decreased healthcare expenditures and mitigated productivity losses. Additionally, the adoption of exoskeletons would enable companies to enhance their flexibility and avoid investing in expensive automation solutions. The mitigation of musculoskeletal issues could enhance the adaptability of workers to various tasks, and enable companies to more effectively accommodate changes in workflow. Consequently, society would bear a lesser burden overall[30].

Activities that require workers to keep their hands lifted for long periods of time represent a major danger, as they can result in shoulder-related illnesses such as tendinitis. Because of the gravitational forces involved, significant moments are created, resulting in compressive stress on the shoulder equivalent to approximately 50% of total body weight. To overcome these issues, the use of arm exoskeletons has grown in popularity across a variety of industrial industries. These exoskeletons enable humans to overcome natural limits in repetitive and heavy jobs. Traditional industrial automation, on the other hand, is hampered by volatility in production processes and rising demand for customized and individualized products. Exoskeletons may provide a solution by supporting workers, improving their performance and strength, and lowering the occurrence of musculoskeletal ailments. Active and passive industrial upper-limb exoskeletons are available. Active exoskeletons use actuators and external power sources to actively help human motions, whilst passive exoskeletons give assistance without the usage of external power sources [31].

2.3.1.3 Arm exoskeleton in gaming and virtual Reality

Virtual reality (VR) technology has grown in popularity and is now widely employed in many facets of daily life, allowing people to interact with virtual surroundings. Users can immerse themselves in high-quality virtual environments exhibited on high-definition screens, as well as realistic audio delivered through surround speakers. Interactive devices such as keyboards, mouse, or gesture control systems can be used to facilitate interactions with the virtual environment. Force-feedback devices, on the other hand, are critical for increasing the sense of realism and interaction. Arm exoskeletons are mechanical structures worn on the upper limb that act as force feedback devices, allowing users to detect touch and force-related sensory input from the virtual environment. They may display reflection pressures at many contact locations, giving users a more immersive virtual reality tele-operation experience. Furthermore, arm exoskeletons can act as power amplifiers, allowing users to control large weights more effectively. The arm exoskeleton can generate significant reflection forces at the shoulder, elbow, and wrist in haptics applications, improving the haptic feedback experience. The arm exoskeleton has a bigger workspace than desktop-type force-feedback systems. Furthermore, depending on the application, it can operate as an active or passive device, increasing its adaptability in VR and haptics applications.[32].

Virtual reality (VR) has the potential to completely transform the area of rehabilitation by providing new avenues for patient participation and customisation. Traditional rehabilitation treatments frequently include repetitive chores, which might result in patient boredom and motivation. VR, on the other hand, enables the introduction of interactive tools such as games and exercises, which can make therapy sessions more engaging and entertaining for patients. Virtual Rehabilitation has arisen as a new type of rehabilitation, combining VR devices and simulations to provide tailored care. This method of classification and taxonomy provides for categorization and taxonomy depending on characteristics such as the patient's field of study, rehabilitation program, or the availability of a therapy team. VR gear is adaptable and can be used to treat a variety of ailments, including stroke therapy, in which hand gloves can be utilized for strengthening exercises and motor development. VR allows patients to actively participate in clinical or home-based studies by establishing an immersive and stimulating environment, resulting in more effective rehabilitation outcomes.[33].

2.3.2 Different design approaches

Arm exoskeletons are wearable technologies that help or augment human arm movements. They can be utilised for rehabilitation, strength enhancement, or assistance with certain tasks. In the creation of arm exoskeletons, numerous design techniques are used.An arm exoskeleton's design approach is determined by its intended purpose, target user population, functional requirements, and design restrictions. Each method has advantages and disadvantages, and continuing research and development is exploring novel design concepts and technology for arm exoskeletons

2.3.2.1 Passive arm exoskeletons

Passive arm exoskeletons have a gravity adjustment mechanism that allows for effortless movements with little muscle exertion. These lightweight exoskeletons have customizable gravity adjustment and a modular architecture, making them adaptable to a variety of uses. The passive device has five degrees of freedom (DoF), with humeral rotation and wrist pro/supination controlled by residual muscle forces or locked at preset settings. Shoulder elevation in the sagittal and frontal planes, as well as elbow flexion, are controlled by residual muscle forces and, if necessary, neuromuscular electrostimulation (NMES), and can be locked throughout the movement. The exoskeleton is made up of six basic components: the wrist, elbow, humeral rotation, shoulder, inclination, and mounting modules. A spring coupled to a cable pull that may be manually adjusted also provides weight relief for the forearm. Upper arm position has little effect on the compensating torque applied at the elbow. However, by inserting a clip, specific movement sequences involving elevated upper arms and flexion/extension of the elbow on a more or less horizontal plane where gravity has no substantial impact on the movement can be blocked.[34]. Figure 2:11 Passive Light-Weight Arm Exoskeleton:

Figure 2.11 Passive Light-Weight Arm Exoskeleton

Passive exoskeletons are generally considered to be a more economical option than active exoskeletons, owing to their uncomplicated structure and decreased intricacy. Passive exoskeletons are characterised by a reduced number of components and the lack of active actuators and intricate control systems, resulting in decreased expenses for both production and upkeep. Frequently, mechanical structures, springs, or counterweights are utilised to furnish aid or reinforcement, thereby obviating the necessity for costly power management systems and batteries. The cost-effectiveness of passive exoskeletons is further enhanced by the streamlined manufacturing processes they entail. The selection of either passive or active exoskeletons must take into account the particular application and functional prerequisites to guarantee the optimal solution is chosen[35].

2.3.2.2 Soft arm exoskeletons

Soft arm exoskeletons, which are also referred to as soft wearable robots or soft exosuits, are a category of arm exoskeletons that employ supple materials and compliant mechanisms to furnish support or enhancement to the user's arm motions. Soft exoskeletons swap out most or all of the heavy, bulky, inflexible components for ones that are soft, light, thin, and flexible. Additionally, some rigid components, such batteries and controllers, are frequently packed into a backpack or used independently to cut weight. These gadgets provide improved user comfort and are lighter and more flexible. Furthermore, because of their features, they are simpler to move and install, enabling the patient to utilize these devices independently and in various locations. To help with movement of the fingers, wrist, elbow, shoulder, hip, knee, and ankle, soft exoskeletons have been developed[36]. Figure 2:12 show soft arm exoskeletons:

Figure 2.12 Soft arm exoskeletons

The essential prerequisites for soft arm exoskeletons include safety, comfort, a wide range of motion, and precise force feedback. Ensuring safety is of utmost importance given that the exoskeleton comes into direct contact with the user. In order to improve safety, structures with low mass and inertia are employed, which integrate high strength along with actuator and/or structural compliance. It is imperative that the device is perceived as safe by prospective users. The provision of comfort is imperative for prolonged usage, as it guarantees that the operator does not encounter exhaustion or unease, even after extended periods of operation. This encompasses factors such as accommodating modifications, optimizing ergonomic features, and facilitating effortless detachment. The exoskeleton ought to offer a wide spectrum of motion, commensurate with the customary human workspace, in order to facilitate users in executing tasks without experiencing any constraints. Precise force feedback is imperative for the operator to accurately perceive and manipulate forces. It is imperative that the exoskeleton possesses ample force resolution capabilities in order to prevent any force discontinuities during movement. By fulfilling these stipulations, soft arm exoskeletons guarantee a secure, pleasant, and organic user encounter, rendering them appropriate for utilization in domains such as convalescence, professional assistance, and daily aid. Continuing research endeavors to enhance the efficacy and reception of soft arm exoskeletons by refining these features[37].

2.3.2.3 Hybrid arm exoskeletons

Hybrid exoskeletons are exoskeletons that use an electrically controlled actuator (e.g., electric motor, pneumatics, hydraulics, etc.) in conjunction with Functional Electrical Stimulation (FES) to give active assistance/resistance to the user. A hybrid exoskeleton may result in a device that is lighter (and hence more portable) than a non-hybrid exoskeleton and can provide larger forces and more precise control than FES alone. As Because the actuator provides some of the forces, the FES should not need to be as strong to create the same movement, decreasing pain at the electrode sites and delaying muscle fatigue. The combination of gadgets may also allow for more exact monitoring of patient progress and automatic fine-tuning of the amount of support provided to the patient. Electromyography (EMG) can offer information on the patient's muscle exhaustion, which, when combined with the consistency of movement provided by the actuators, could be valuable for tracking patient improvement throughout multiple sessions. This data can then be utilized to manage the amount of support provided by the exoskeleton to the patient, as well as the FES settings and the ratio of FES support to mechanical actuator support, in order to provide the patient with an adequately difficult workout[38]. Figure 2:13 show Hybrid arm exoskeletons:

Figure 2.13 Hybrid arm exoskeletons

The hybrid exoskeleton described here is intended for passive upper-limb rehabilitation, which is widely used in the early stages of the rehabilitation process. The system comprises of a flexible wearable component that uses a fabric coupling to link a nylon-covered steel cable to the user's arm. The cable's opposite end is connected to a pulley connected to motor m1, which is part of the exoskeleton's end effector. The exoskeleton can facilitate arm movements for the user by altering the cable length by winding or unwinding it over the pulley and suitably situating the rigid structure's end effector. This exoskeleton is classified as hybrid because it includes both rigid parts that are anchored to the floor and a wearable coupling that the patient wears. Not only does the stiff part provide exact alignment of the exoskeleton's end effector, but it also houses the control electronics.

A combination of hybrid functional electrical stimulation (FES) and robotic control is necessary to provide adequate help for generalized upper limb movements. Two basic actuation subsystems are used in the hybrid FES-exoskeleton system. FES is delivered by the first subsystem using a transdermic electrical stimulation system with eight bipolar stimulation output channels. Two of these channels are for elbow flexion/extension and two are for wrist flexion/extension. To achieve different levels of output using the FES subsystem, the amplitude and frequency for each channel remain constant while the pulse width is adjusted. Integrating these techniques in an optimal manner that enables comprehensive upper limb movement assistance requires the development of a unified methodology for hybrid FES and robotic control of upper limb reaching actions.[39].

2.3.3 Challenges and limitations of existing exoskeleton arm designs

Exoskeleton arm designs have developed as a promising technology with the potential to improve human capabilities in a variety of disciplines, including healthcare and rehabilitation, as well as industrial uses. These devices are designed to improve the strength, endurance, and precision of human arms, allowing people to perform physically demanding activities more efficiently or supporting those with limited mobility in recovering their independence. Despite their intriguing potential, contemporary exoskeleton arm designs have a number of challenges and limitations that prevent widespread adoption and optimal performance.

2.3.3.1 Power-to-weight limitations

Exoskeletons' mobility potential can be limited by their power-to-weight ratios, which can lead to increased energy consumption. The gravity balance method presents a viable solution to tackle the aforementioned challenge. Exoskeletons have the potential to decrease their energy consumption by utilising natural forces, such as gravity, to stabilise loads and motions. The aforementioned methodology efficiently reduces the workload on the exoskeleton's energy source, thereby augmenting the system's overall efficacy. Consequently, the exoskeleton has the capability to function for prolonged periods of time while providing enhanced user-friendliness. The utilisation of the gravity balance method in exoskeleton design constitutes a noteworthy progression, facilitating enhanced and sustainable mobility, while optimising the advantages of exoskeleton technology[40].

2.3.3.2 Safety concerns

The design of exoskeletons places significant emphasis on safety, particularly with regard to variables such as fitting duration and velocity. Acknowledging these constraints, current clinical trials are underway to tackle these issues and optimise the advantages of exoskeletons within the context of rehabilitation. The objective of these trials is to enhance the fitting procedure, with the goal of achieving optimal comfort and security for individuals with varying body types who wear exoskeletons. Furthermore, the trials aim to optimise the velocity and agility of exoskeletons, facilitating seamless and organic motions that correspond with the user's volition. By means of meticulous assessment and enhancement, these clinical trials make a valuable contribution towards the progression of exoskeleton design, the advocacy of safety, and the optimisation of the beneficial effects of exoskeletons in the field of rehabilitation[41].

2.3.3.3 Prohibitive cost

The expensive price of exoskeletons is a significant obstacle to their broad availability in medical environments. The cost is partly due to the extensive training needed for professionals to supervise and assist individuals with spinal cord injuries who use exoskeletons. Adequate training is essential for ensuring the safety and welfare of users during rehabilitation sessions. The training process includes gaining detailed knowledge of exoskeleton operation, comprehending the unique requirements and constraints of each patient, and becoming proficient in the relevant methods for providing aid and reinforcement. Healthcare providers can improve the accessibility of exoskeleton technology for people with spinal cord injuries by providing thorough training programmes[42].

2.3.3.4 Non-neutral trunk posture

The use of anthropomorphic design in upper extremity exoskeletons may unintentionally restrict users. This design approach could limit the natural range of motion in the arms, back, and neck, and may also restrict non-neutral trunk posture. Users may feel uncomfortable, have limited mobility, and strain their musculoskeletal system. Innovative design strategies are being explored to tackle these issues. The mentioned items are exoskeletons that can be adjusted to fit various body types and movements. Exoskeleton designs can enhance the effectiveness and usability of upper extremity exoskeletons in various applications by prioritising user comfort, natural posture, and a broader range of motion while minimising restrictions[43].

2.4 Comparison of previos Studies

Table 2:3 comparison of previos studies:

Title	Author's	Method/ sollution
An EMG-Controlled Hand Exoskeleton for Natural Pinching	Lenny Lucas* , Matthew DiCicco* , and Yoky Matsuoka	This article presents a hand exoskeleton designed to be controlled by electromyography (EMG) signals, improving pinch force and accuracy. The study highlights the potential of EMG-based control systems for assisting individuals with hand disabilities and discusses the challenges in developing effective control mechanisms[44].
Control of Newly-Designed Wearable Robotic Hand Exoskeleton Based on Surface Electromyographic Signals	Ke Li, Zhengzhen Li1, Haibin Zeng2 and Na Wei	This journal article introduces a wearable robotic hand exoskeleton controlled by surface electromyographic (sEMG) signals. The exoskeleton allows individuals with hand disabilities to perform daily tasks through intuitive control using sEMG signals. Evaluation trials demonstrate accurate gesture recognition and user satisfaction, indicating its potential for improving the quality of life for individuals with hand impairments[45].
Design, Fabrication, and Control of an Upper Arm Exoskeleton Assistive Robot	Reza Shisheie	This article discusses the design and control of an upper arm exoskeleton for assisting individuals with arm disabilities. Modular customization and position-force sensing contribute to its effectiveness. Further research is needed to improve design and control for enhanced quality of life[46].

Modelling and EMG based Control of Upper Limb Exoskeletons for Hand Impairments	Norhafizah bt Abas	This study develops a control system for an upper limb exoskeleton to assist individuals with hand impairments using electromyography (EMG) signals. Experimental results demonstrate the system's effectiveness in assisting users with hand impairments in performing tasks. The article highlights the need for further research to enhance the accuracy and reliability of exoskeleton control systems, aiming to improve the quality of life for individuals with hand impairments[47].
The Development of a Low-Cost Exoskeleton Arm for Rehabilitation Use	Ramon Sargeant; Adrian Als; Evrico Inniss	The study introduces a customizable and adaptable exoskeleton arm for rehabilitation. It utilizes EMG signals and affordable 3D printing materials. Experimental results show its effectiveness, emphasizing the need for improved control system accuracy and reliability to assist individuals with arm impairments..
A gesture-based telemanipulation control for a robotic arm with biofeedback-based grasp	Yassine Bouteraa and Ismail Ben Abdallah	The article introduces a control system for a robotic arm that combines gesture-based telemanipulation and biofeedback-based grasp. Experimental results demonstrate the system's effectiveness in task performance. The authors highlight the potential of this approach for enhancing control and safety in robotic arm applications, emphasizing the need for further research to optimize its design and implementation.

2.5 Finding and Summary

The summary of the literature review is about Exoskeleton technology, EMG sensors and muscle signal analysis, and actual exoskeleton arm designs are all included in the summary. The first section delves into the history, idea, types, uses, benefits, and major components of exoskeleton systems. The second section discusses electromyography (EMG) sensors, including their introduction, concepts, signal gathering methodologies, kinds, and noise reduction strategies. Finally, the third section discusses contemporary exoskeleton arm technologies, including their applications, design methods and problems and constraints.

From this, an exoskeleton project could be implemented in various applications depending on the needs and feasibility. This approach is taken to make human jobs easier and more practical compared to the without using exoskeleton as it could solve a real-life problem. For this project, there are 3 main factors that make this project successful, which are selection of hardware and electronic parts, position of the motor and sensor and the structure of the exoskeleton.

CHAPTER 3

METHODOLOGY

3.1 Introduction

For this chapter, research methodology on the design and development an exoskeleton arm is discussed. The project flow for this project will also be described in this chapter. Basically, the system can be divided into three parts, which are electronic and hardware design, mechanism, and calculation of torque.

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3.2 Project Flow

This project started out with research into exoskeleton design and development. The system's required sensors, microcontroller, and motor are then the subject of research. Create a circuit schematic and CAD drawing after that. The circuit diagram is constructed after the appropriate electronic, microcontroller, and motor are selected, and the design's verification comes next. The characteristics and datasheets of the sensors are evaluated after the design has been validated. After that, components of the prototype and a microcontroller programming scheme can be created. The hardware is eventually tested once all the programming has been confirmed. Figure 3:1 show the project flow:

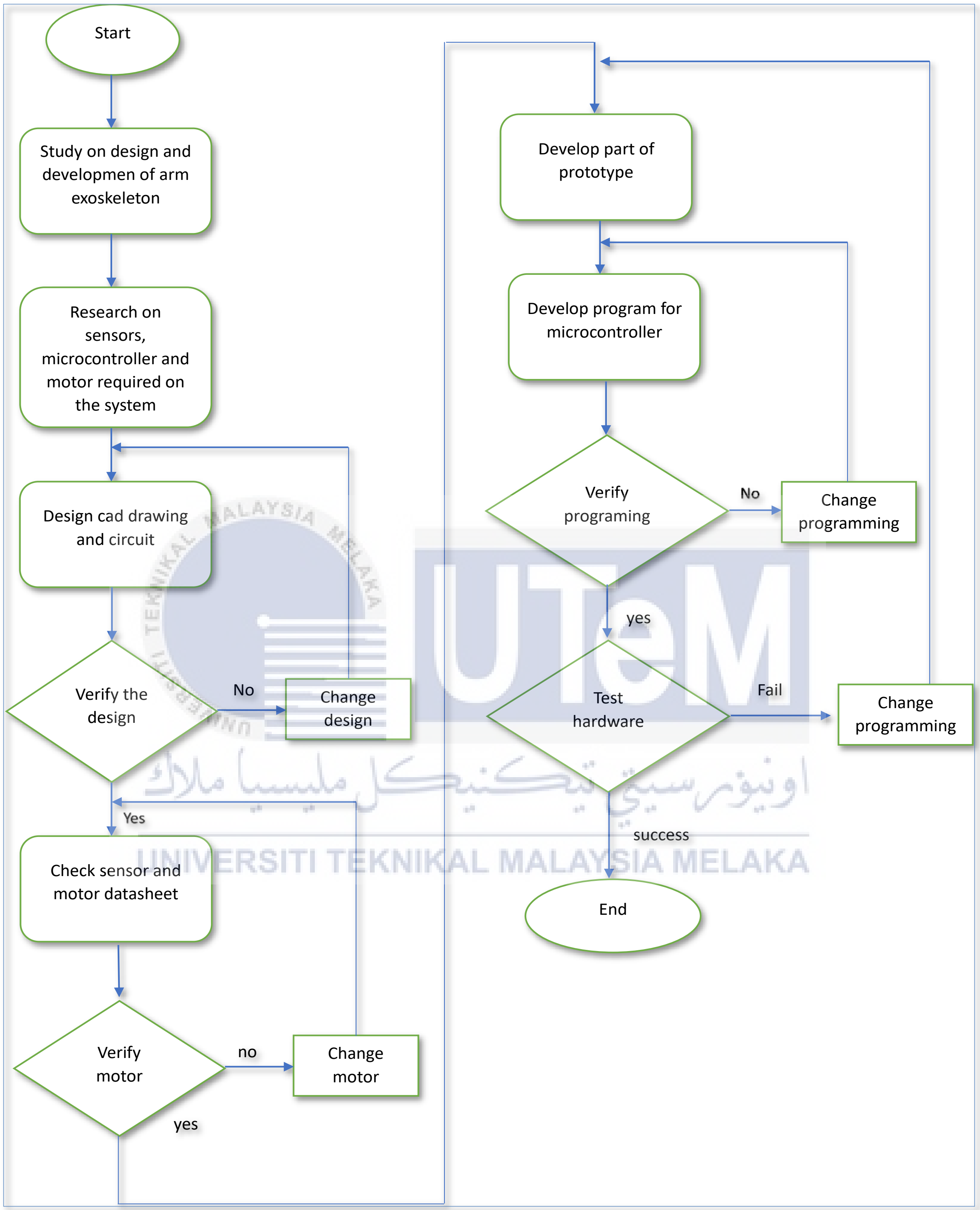

Figure 3.1 Project flow

3.3 Electronic and Hardware Component

The system's electronic components begin by using sensors, notably electromyography (EMG) sensors, to gather data from the muscles while performing item transportation duties. These sensors capture data continually and send it to an Arduino UNO microcontroller for processing. To transform sensor readings into the appropriate unit, the microcontroller uses an algorithm or formula within the Arduino Integrated Development Environment (IDE). After processing the data, the microcontroller communicates with a power window motor, which creates the required torque. This torque helps humans to carry the weight of the task with ease. block diagram of the system is shown at Figure below. Figure 3:2 show block diagram of the system

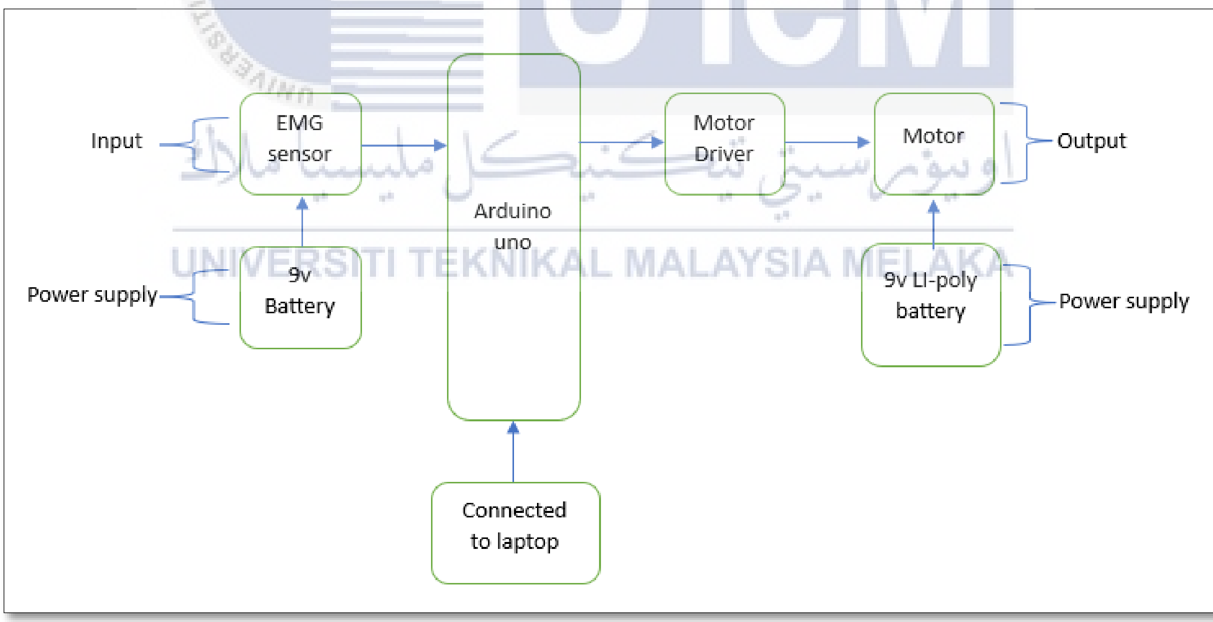

Figure 3.2 Block diagram of the system

3.3.1 Electromyography (EMG) Sensor

Basically, when design and development of an exoskeleton arm determines the sensor, it plays a significant role. So, for this project the EMG sensor has been chosen as the sensor for the exoskeleton system. For the exoskeleton project especially, the carrying object task is mainly focused on the human muscle, that means that the EMG sensor is the suitable sensor that needs tobe used for this project instead of using the pressure sensor or else. An EMG sensor, also known as an electromyography sensor, is a device that detects small electrical signals produced by your muscles when you move them. This includes lifting arm up, or even the simplest of movements like moving a finger. These showed that an EMG sensor is suitable for the task that involves human muscle work.

Generally, EMG sensors have two types which are sEMG sensors (surface electrodes) and Intramuscular EMG. For the sEMG sensor, ‘s’ means by the surface so that the sensor only takes the data from the surface of human skin. Next, for the Intramuscular EMG takes measurement through inserting a monopolar needle electrode through your skin and into the muscle tissue and it is a common way for EMG sensor.

An EMG sensor works in a few ways. The process begins when it starts by placing the EMG placement at the focusing muscle. Next, when the muscle moves it will produce electrical activity therefore the electrode will detect electrical signals. Then the electrical activity detected is then displayed via the form of waves on a monitor. The working principle is shown in Figure below.

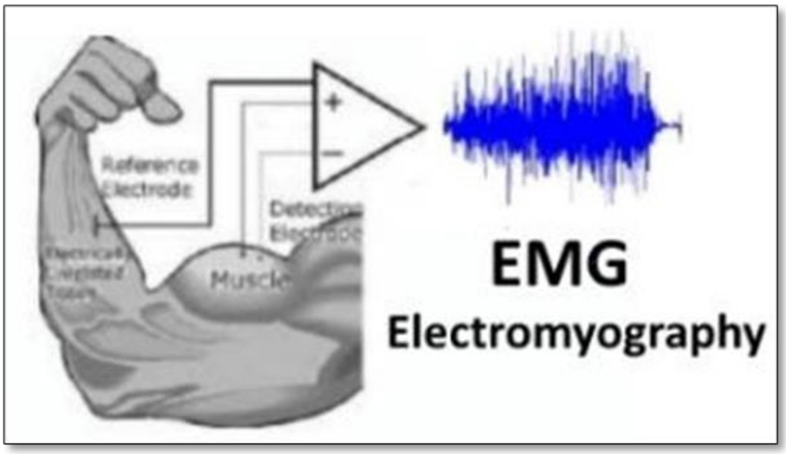

Figure 3.3 Principle of Electromyography Sensor

EMG sensor as shown in Figure 3:4 is commonly used is the biomedical field. Normally, helping the doctor diagnose muscle and nerve disorders of patients for early prevention or treatment. And EMG sensor also been used for a control signal for prosthetic devices like hands, arms, and lower limbs. The specification of the sensor is shown in Table 3.1.

Figure 3.4 EMG sensor

Table 3:1 Specification of EMG sensor

Operating voltage (v)	**±5**
Audio-style plug	**3.5mm jack**
Length of connecting cable (m)	**1**
Length (mm)	**33.5**
Width (mm)	**26**
Height (mm)	**12**
Weight (g)	**40**

3.3.2 Patch EMG (Electromyography) sensor

A patch EMG (Electromyography) sensor is a wearable device that captures and records electrical signals produced by muscles during muscular contractions. Patch EMG sensors are typically small, sticky patches that are applied directly to the skin's surface overlaying the muscles of interest. The sensor detects electrical activity generated by muscle fibres by using electrodes inserted within the patch. These electrodes detect electrical impulses generated by muscles when they contract or relax. These signals are subsequently amplified and processed by the patch EMG sensor to offer information about muscle activity.

Patch EMG sensors are commonly used in sports and fitness monitoring, biomechanics research, physical rehabilitation, and assistive technology. They can reveal important information on muscle activation patterns, muscular fatigue, and muscle coordination during movement. Patch EMG sensors have the benefit of being non-invasive, as they can be readily put and removed without causing discomfort or agony. It is also usually wireless and can send the data it collects to a computer or mobile device for additional analysis. Figure 3:5 show patch EMG (Electromyography):

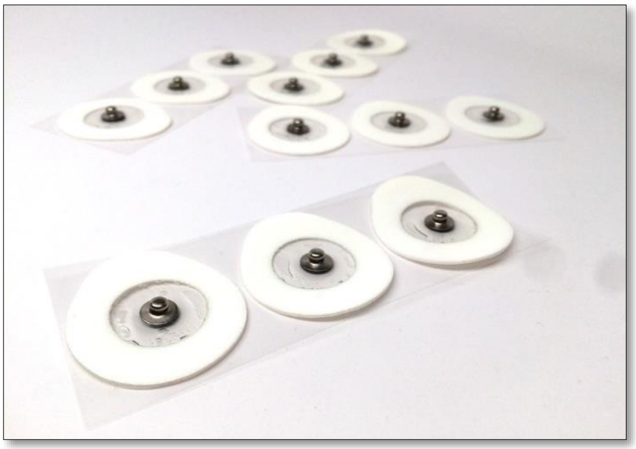

Figure 3.5 Patch EMG (Electromyography)

3.3.3 Servo Motor

This kit's actuator is an electric servomotor with a gear and control electronics housed within the motor casing. A potentiometer included inside the servomotor measures the rotation angle (position) of the motor's shaft. The servomotor has three wires in total: two for the power supply (red and brown) and one for the servo motor control signal (orange).

When a command is given on the control wire (e.g., from the main microcontroller), the servomotor's integrated control system may already execute basic (low-level) control, such as moving to a desired angle. PWM (pulse width modulation) is used to encode the required angle. The intended angle of the motor is related to the width (duration) of an electric pulse transmitted to the servomotor via the control wire in PWM encoding. This signal is given on a frequent basis to keep the motor at the proper angle.

The specification of the servo motor used is shown in the Table

Figure 3.6 Servo motor

Table 3:2 Specification of the Servo Motor

Parameter	Specification
Gear	Full metal
Spline	25T
Motor	DC motor
Operating Voltage	DC 5.0~8.4V
Working Frequency	1520µs/330Hz
Stall Torque (5.0V)	19.5 kg.cm (201.40 oz/in)
Stall Torque (6.0V)	20.8 kg.cm (233.35 oz/in)
Stall Torque (7.4V)	25.0 kg.cm (277.80 oz/in)
Stall Torque (8.4V)	27.5 kg.cm (298.63 oz/in)
Dimensions	40*20*41.1mm
Weight	66g
Connector Wire Length	JR 300mm

3.3.4 Microcontroller (Arduino Uno)

The Arduino UNO is indeed a widely used microcontroller board for development purposes. It is based on the ATmega328P microcontroller, which is an 8-bit AVR architecture microcontroller manufactured by Atmel (now owned by Microchip Technology). The ATmega328P is a versatile microcontroller that provides a good balance between performance and cost.

The Arduino UNO board includes numerous critical components that support the ATmega328P microprocessor and allow it to be used in a variety of applications. The crystal oscillator, which is normally set at a frequency of 16 MHz, is an important component. This oscillator produces a precise clock signal, allowing the microcontroller to perform tasks with perfect timing and synchronisation. The board also has a voltage regulator, which converts the input voltage (often varying from 7 to 12V) to a steady and controlled 5V or 3.3V, depending on the version of the board. This regulated power supply guarantees that the microcontroller and other associated components receive consistent and stable power, allowing them to operate and perform properly.

Another important aspect of the Arduino UNO is serial connectivity. The ATmega328P microcontroller includes hardware support for several serial communication protocols, including UART (Universal Asynchronous Receiver-Transmitter). The board incorporates USB-to-serial conversion hardware, making it simple to connect the Arduino UNO to a computer for programming and communication.The Arduino UNO has a variety of I/O pins that are essential for interacting with other components and sensors. These pins can be set as digital input or output, allowing the microcontroller to read sensor signals or control other devices. Furthermore, several of these pins provide PWM (Pulse Width Modulation) output, which allows for the production of analog-like signals for applications like as controlling motor speed or LED brightness.

The Arduino UNO incorporates a reset button to help with programming and system control. This button is used to reset the microcontroller or to launch the bootloader, which enables for programme uploading. It is useful for building and debugging Arduino-based projects. Finally, the Arduino UNO board includes many built-in LEDs for visual feedback. The microcontroller, for example, can drive an onboard LED attached to pin 13. It can be used for a variety of things, such as indicating programme running, debugging, or generating a visual user interface.

The ATmega328P is a versatile microcontroller that provides a good balance between performance and cost. The pinout diagram is illustrated in Figure 3:7.

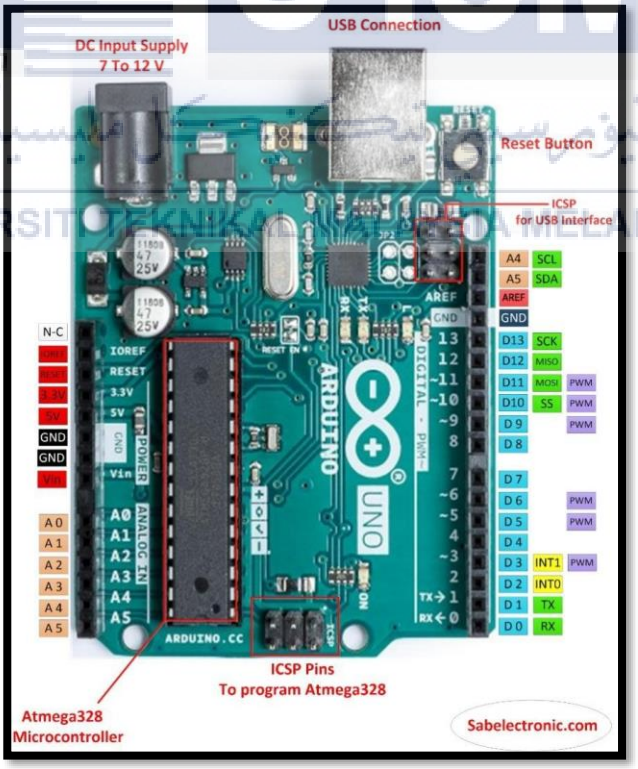

Figure 3.7 shown Pinout of Arduino Uno

3.4 Mechanical design of arm exoskeleton

The mechanical design of an arm exoskeleton is crucial for ensuring user support, mobility, and functionality. When designing an arm exoskeleton, there are several important factors to consider.

To begin, the exoskeleton should be ergonomically built to properly suit the user's arm and minimise discomfort and fatigue during operation. It should consider the arm's natural structure and range of motion, allowing for smooth and natural movements while reducing strain on joints and muscles.

Another important factor is the use of lightweight and long-lasting materials. Carbon fibre, aluminium alloys, and composites can give strength without adding extra weight, making the exoskeleton more comfortable to wear and minimising user fatigue.

The joint mechanics of the exoskeleton should closely mirror natural arm movement. To allow flexion, extension, and rotation at the elbow, wrist, and other important joints, hinges, linkages, or rotational devices can be used. This enables for a wide range of motion while still maintaining stability and control. The exoskeleton's functionality is dependent on actuation and power transfer technologies. Actuators can be electric motors, pneumatic or hydraulic systems, or a combination of these. The mechanical design should enable precise and responsive control of the exoskeleton's movements by ensuring efficient power transmission from the actuators to the joints.

It is critical to include sensors and feedback systems so that the exoskeleton can deliver real-time input and adapt its movements accordingly. Position sensors, force sensors, and electromyography (EMG) sensors can be utilised to detect muscle activity and collect reliable data for control and feedback. The placement and integration of these sensors should be considered in the mechanical design. The design of an arm exoskeleton must prioritise safety. Limit switches, mechanical stops, and torque control systems can help to avoid excessive joint motions, protect the user from overexertion, and keep the exoskeleton operating within safe boundaries.

Finally, the mechanical design should be adaptable and customizable to accommodate different arm sizes and functional capacities. To provide a correct fit and flexibility to varied user profiles, adjustable straps, fasteners, or modular components might be included.

3.4.1 Arm braces

An arm brace can be used as part of the mechanical construction of the exoskeleton. The arm brace in an arm exoskeleton gives support and stability to the user's arm while also assisting in the alignment of the mechanical components of the exoskeleton with the user's limb. An arm exoskeleton's arm brace is often custom-designed to fit the user's arm pleasantly and securely. It could be composed of lightweight and long-lasting materials like carbon fibre or aluminium to give strength without adding too much weight. Typically, the brace is adjustable to suit varied arm sizes and assure a proper fit.

The arm brace in an arm exoskeleton serves as a stable connection point between the user's arm and the mechanical actuators. It helps distribute forces and torque generated by the actuators across the user's arm, reducing the risk of pain or injury. By incorporating an arm brace into the design, the exoskeleton can be securely attached to the user's arm, allowing precise movement and coordination. The brace ensures alignment between the mechanical components of the exoskeleton and the user's arm, enabling effective force transfer and support during arm movements. Additionally, the arm brace provides added support and protection for individuals with arm deficiencies or injuries by stabilizing the arm and reducing excessive joint movement or misalignment.

Figure 3.8 of Arm Braces

3.5 Software Development

The following section provides a detailed account of the software that will be utilized for the purpose of coding and simulation. This software will play a crucial role in ensuring the effective and efficient monitoring of the project's system. It is imperative that the software chosen for this purpose is comprehensive in nature, and is capable of providing a holistic view of the system being monitored. The software will be responsible for overseeing all aspects of the project's system, and will be instrumental in identifying any potential issues or areas of concern. Therefore, careful consideration has been given to the selection of the appropriate software, in order to ensure that it is capable of meeting the project's requirements.

3.5.1 Arduino IDE

The Arduino IDE, an acronym for Integrated Development Environment, is a software application that is tailored to the programming and development of applications for Arduino boards. The platform offers a facile graphical user interface and a suite of utilities that facilitate the process of composing, compiling, and transferring code to Arduino microcontrollers. The Arduino Integrated Development Environment (IDE) is a software application that is accessible without charge and has an open-source license. It can be utilized on various operating systems such as Windows, Mac, and Linux. Its simplicity and accessibility make it a popular choice among both novice and seasoned developers.

The Arduino IDE is a full development environment for programming Arduino boards. It includes a code editor with features like syntax highlighting, auto-indentation, and code completion to make writing and editing code easier. Arduino programmes, known as sketches, are made up of two key functions: setup() and loop(). The IDE includes templates and examples to help newcomers get up and running quickly. Additionally, the IDE features a library manager that allows users to search for, install, and manage external libraries. These libraries offer pre-written code that simplifies programming for various components and sensors. The IDE also includes a serial monitor tool for communicating with the Arduino board via the serial connection, allowing data interchange, code debugging, and sensor monitoring.

The board manager assists in the selection of the suitable board type and in the installation of required drivers and firmware. The IDE manages compilation and upload operations via a USB connection or other compatible means, making it easier to upload code to Arduino boards. Finally, the IDE provides a wealth of examples and reference resources to assist users in grasping Arduino programming ideas and utilising various features and capabilities. Figure 3:9 show the start up Arduino ide:

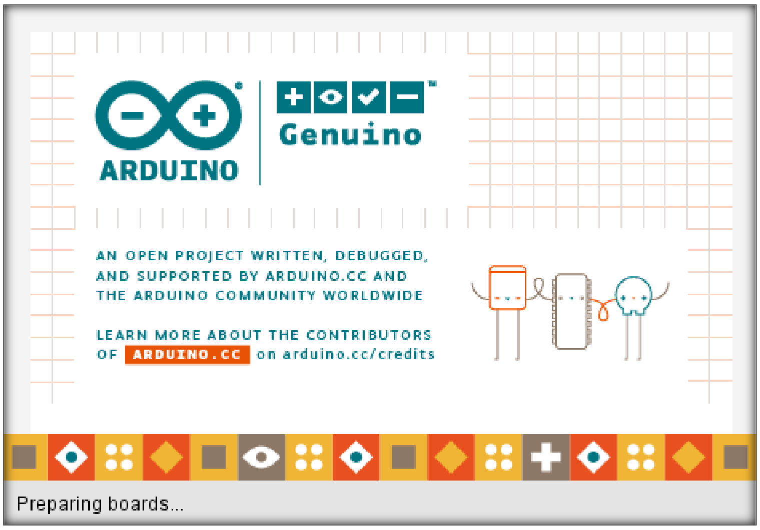

Figure 3.9 start up Arduino ide

3.5.2 Serial Monitor

The Serial Monitor is a useful tool included with the Arduino IDE that allows communication between an Arduino board and a computer via the serial port. Its principal purpose is to allow data transmission and receiving between the two devices. Debugging is one of the Serial Monitor's primary applications. It allows you to output debugging messages from your Arduino code, allowing you to see variable values, programme flow, and condition tests in real time. This aids in discovering and correcting errors in your code.

Furthermore, the Serial Monitor allows data to be sent between the Arduino board and the computer. It allows you to monitor sensor readings, display output values, and send data to your computer for additional processing. This feature is especially beneficial in applications requiring real-time data processing or remote monitoring. Beside that, the Serial Monitor allows for user interaction with the Arduino board. You can design interactive applications in which users can submit input values or commands to control the behaviour of the Arduino board by prompting them for input through the monitor.

To use the Serial Monitor, connect your Arduino board to your computer via USB and pick the proper serial port from the Tools menu in the Arduino IDE. Once connected, open the Serial Monitor by clicking the magnifying glass icon in the top-right corner of the IDE or by selecting "Serial Monitor" from the Tools menu. Set the baud rate to match your Arduino code and send/receive text or numerical data through the input field at the top of the window using the Serial Monitor.

In summary, the Serial Monitor in the Arduino IDE is critical for debugging, data sharing, and user interaction during Arduino project creation and testing. It improves the productivity and efficacy of software development by simplifying communication between the Arduino board and the PC.

Figure 3.10 Serial Monitor

3.6 System Component Configuration

The arm exoskeleton prototype design, circuit connection, and EMG sensor data analysis are the first stages of our System Component Configuration. These breakthroughs lay the groundwork for moving our project forward. Further iterations and improvements will build on these components, contributing to the evolution and refinement of the arm exoskeleton system.

3.6.1 Arm exoskeleton design

According to Figure 3.11, our design is based on the structure of a human arm, with variable diameter rings. Two supports have been carefully placed to assist easier object carrying. To achieve force balance, each ring is securely linked to the framework. This intelligent design not only mimics the natural shape of a human arm, but also provides item handling functionality. The adaptability of varied diameters and the installation of supports improve both the structural integrity and functional efficiency of our arm-inspired design.

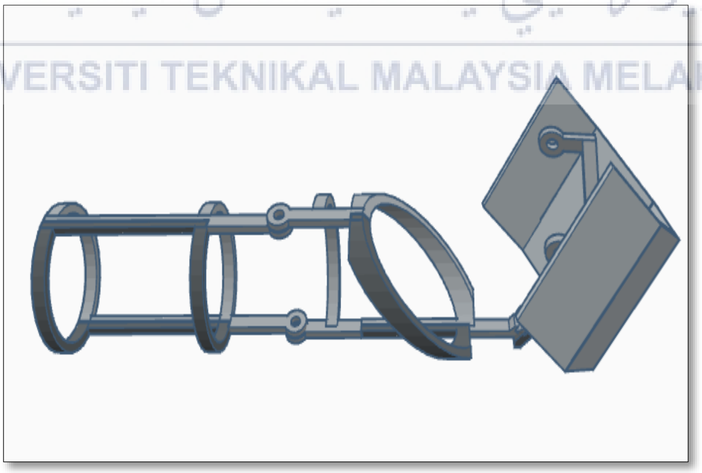

Figure 3.11 Arm exoskeleton design

3.6.2 Circuit connection

Make a connection circuit like the oneare shown as figure 3:12.There are two power supplies or batteries to generate +Vs and -Vs. Connect the negative side of the first battery to the positive side of the second battery first. As a result, an electric ground is formed for power delivery. As a result, the first battery's positive end is +Vs and the second battery's negative end is -Vs. After doing the connection, attach surface EMG sensor to the user.

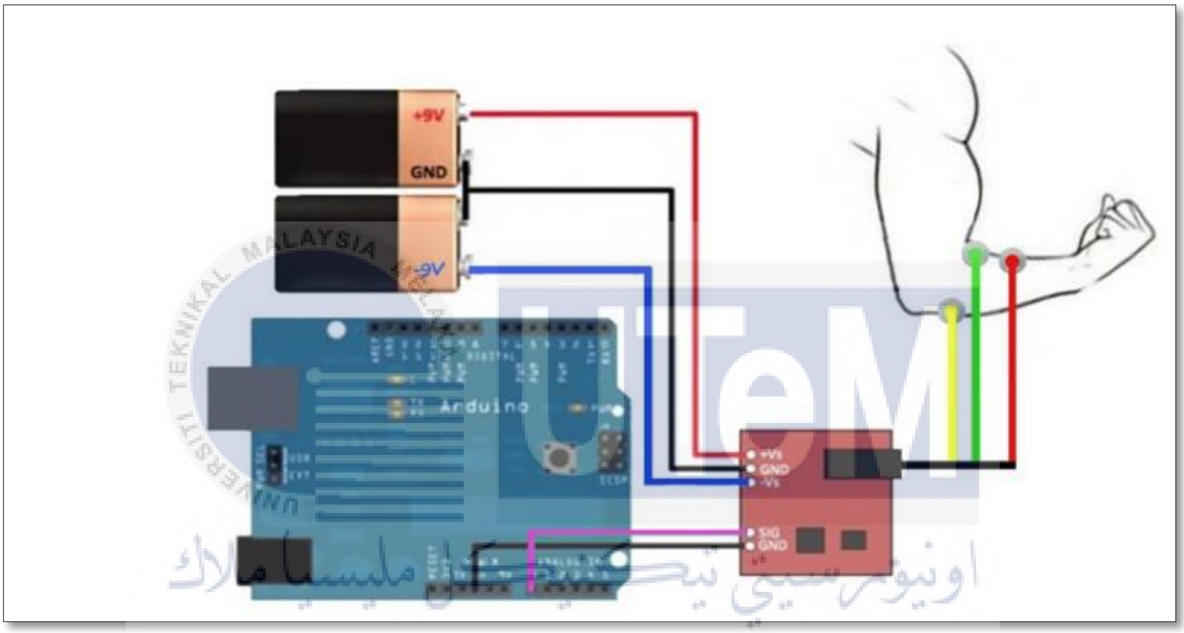

Figure 3.12 Connction circuit and attach to the user arm.

3.6.3 EMG sensor signal

The electromyography (EMG) sensor is a device that measures the electrical activity generated by muscle fibres during contraction. The output signal produced by the EMG sensor is indicative of the magnitude of the electrical signal generated by the muscle. Specifically, the amplitude of the EMG signal is directly proportional to the amount of energy produced by the muscle during contraction. Therefore, a higher amplitude signal corresponds to a greater amount of energy produced by the muscle.

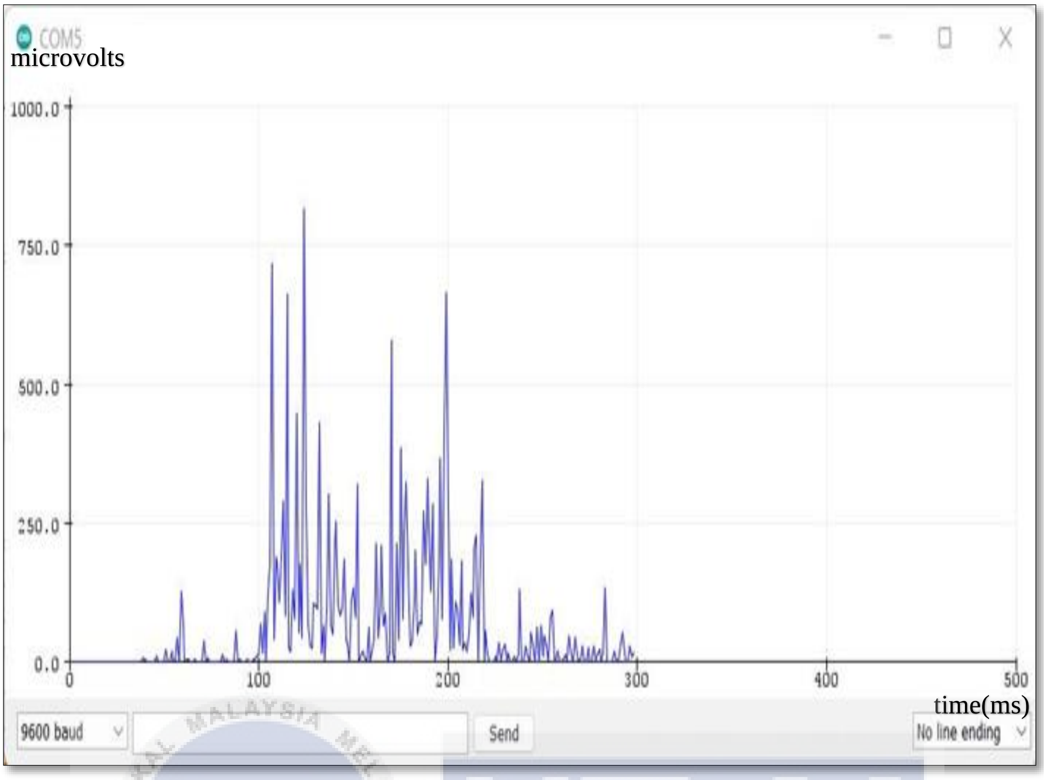

Figure 3.13 Signal EMG sensor when study lift a 5kg load up and down.

3.6.4 Flowchart Of the System

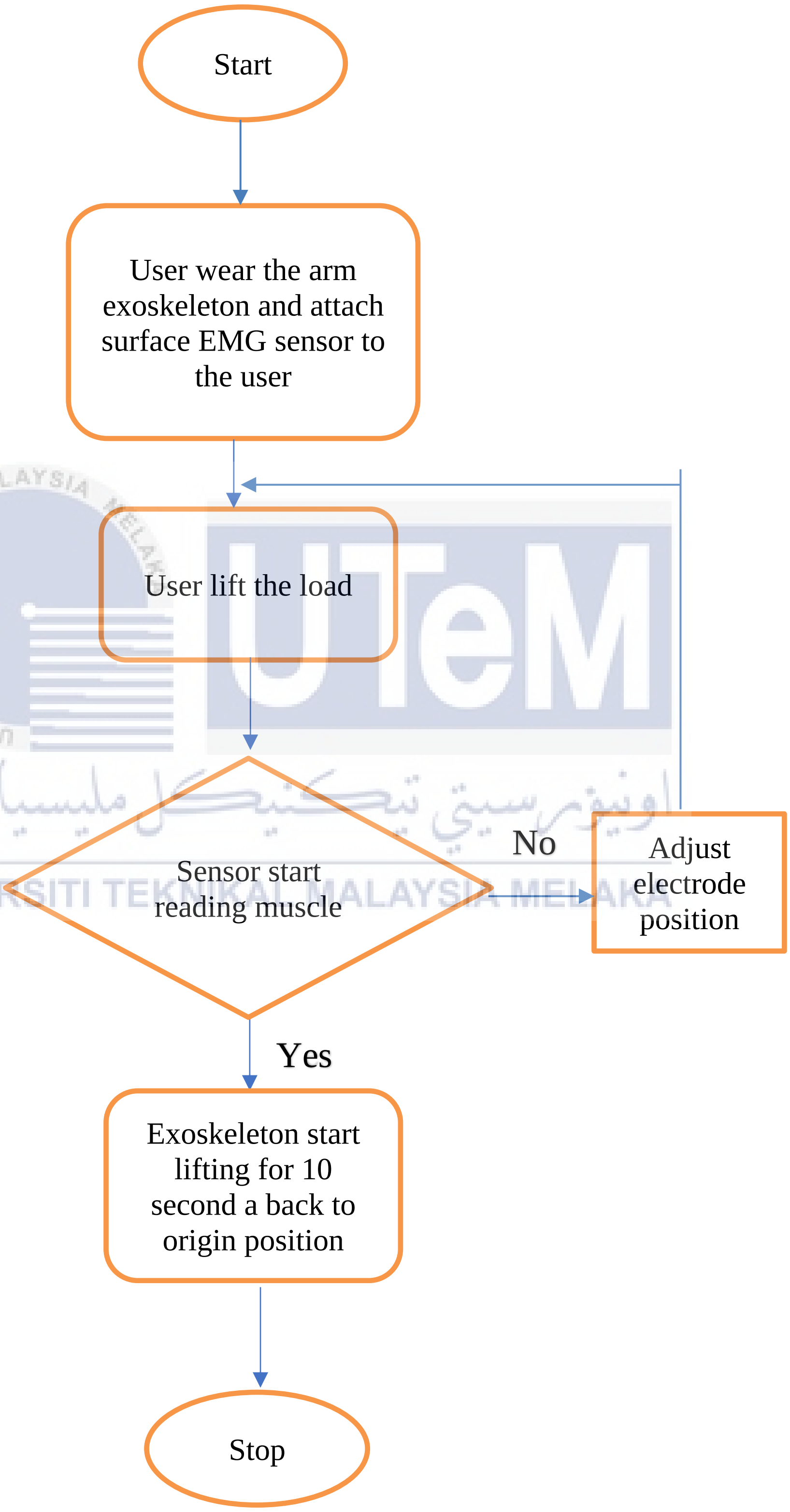

Figure 3.14 Flowchart of Expected Result for this project

In this procedure, a user wears an arm exoskeleton and connects a surface electromyography (EMG) sensor to assess muscle activation. Initially, the user lifts a burden, and the sensor detects muscle signals. If the sensor is having difficulty capturing signals, the electrode placements are modified to provide precise readings. Once successful muscle readings are acquired, the exoskeleton commences a lifting sequence for 10 seconds, supporting the user in carrying the burden. After this time, the exoskeleton returns to its previous place. This flowchart outlines a simple yet effective approach for ensuring that the exoskeleton responds to the user's muscular action, giving support for the given duration, and then returning to a resting state, thereby improving the overall usability of the arm exoskeleton.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

This chapter describes the project's outcomes, with a focus on hardware implementation. It provides insights into the concrete outputs and practical applications achieved through the creation and integration of physical components. The emphasis on hardware implementation emphasises the hands-on and practical components of the project's execution.

4.2 Mechanical parts Development

4.2.1 Mechanical design parts

In the hardware development phase, the arm exoskeleton design attained important breakthroughs, employing modern modelling approaches such as parametric design and assembly to solve intricate difficulties. The prototyping process began with a critical 3D-printed test component, which laid the groundwork for materialising conceptual concepts. The overall design of the arm exoskeleton was completed successfully, with first tests of 3D-printed components assuring good fit and functionality. A particular emphasis on 3D printing using PLA Plus underlined a dedication to durability and toughness. Printer calibration improved print quality and structural integrity, while extensive testing confirmed PLA Plus compatibility, emphasising the commitment to developing a long-lasting and user-friendly arm exoskeleton. The model of arm exoskeleton show in figure 4:1.

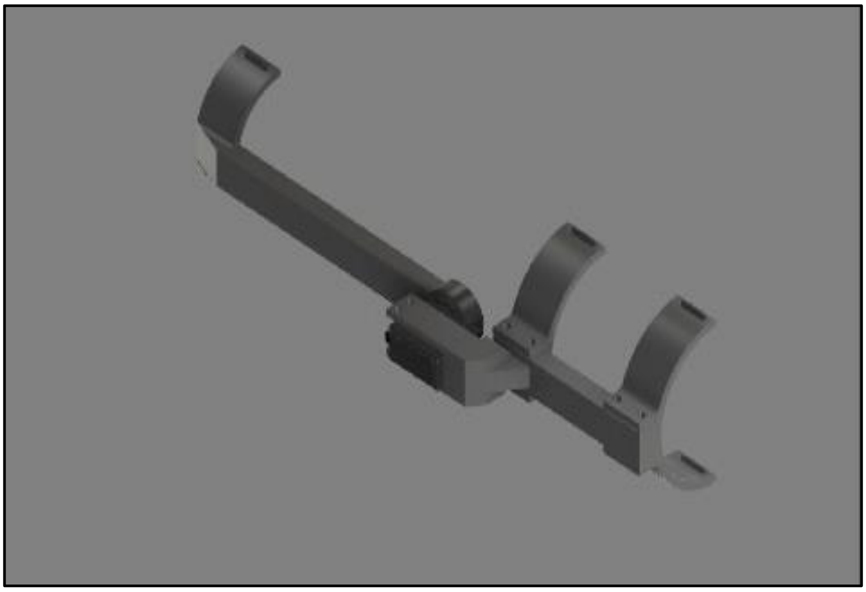

Figure 4.1 Arm Exoskeleton Design

Based on figure 4:2, the Motor Adapter is a crucial component responsible for linking and securely fastening the servo motor to the designated structure. Its role is to facilitate a stable connection, ensuring proper alignment and functionality, thereby enabling the servo motor to effectively drive and control specific mechanical actions within the system.

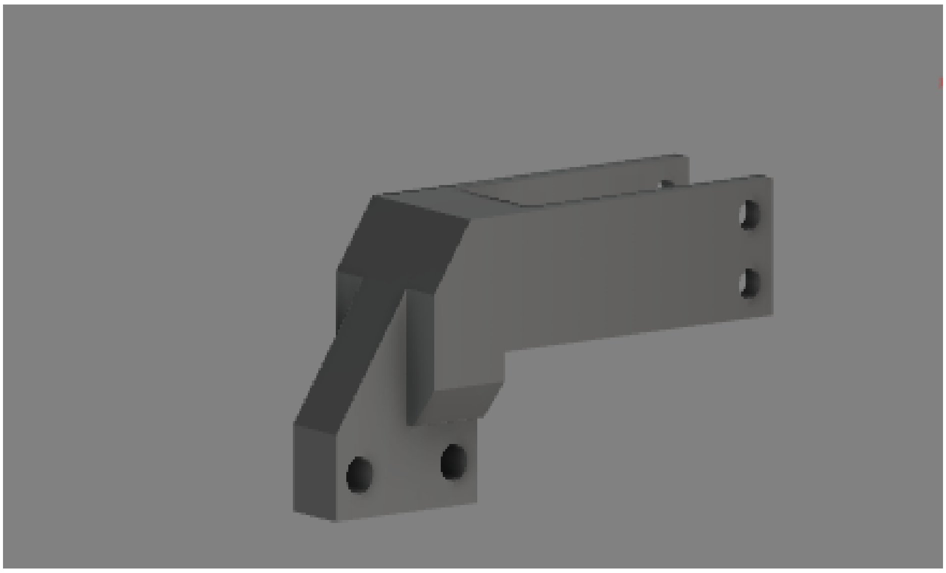

Figure 4.2 MotorAdapter

Based on figure 4:3, the Upper Arm Cuff is a wearable component for the upper arm region that is meant to be produced in triplicate. These cuffs are designed to wrap over the upper arm and create a comfortable and secure fit. Their goal is to improve user comfort and assist correct device connection to the upper arm area.

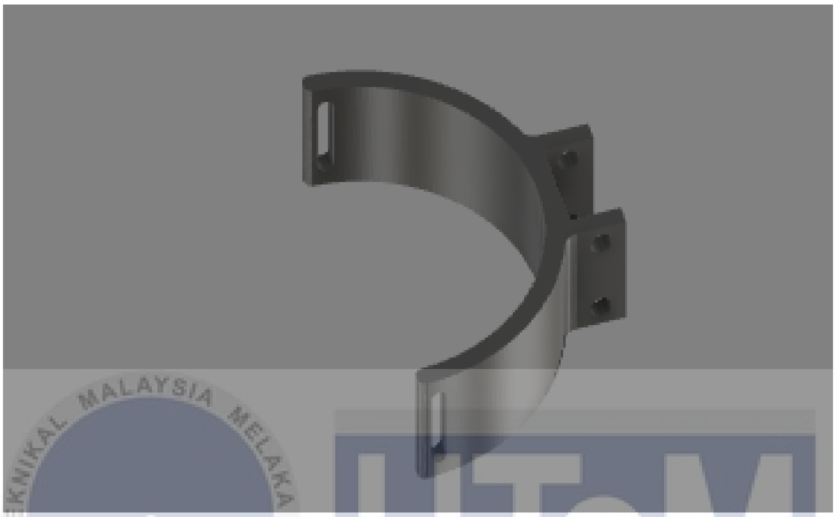

Figure 4.3 Upper ArmCuff

Based on figure 4:4, the Upper Arm Segment is the connection that connects the two Upper Arm Cuffs to the Motor Adapter. This important component serves as the structural bridge, enabling assembly cohesion and stability. It is critical in constructing the structure that incorporates the cuffs and motor adapter, adding to the device's overall operation.

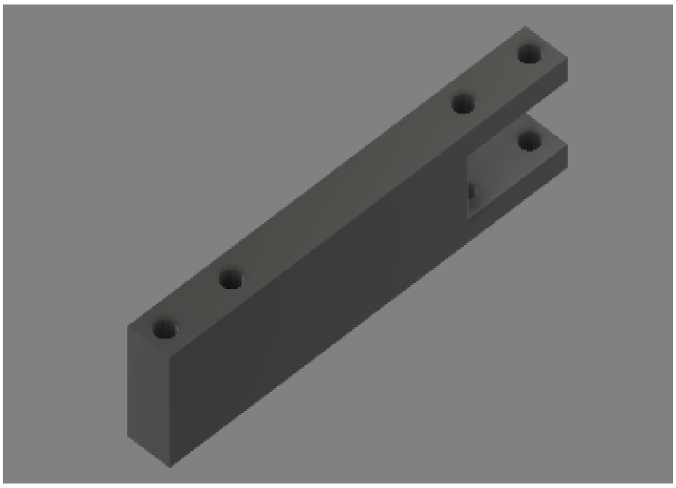

Figure 4.4 Upper Arm Segment

The Lower Arm Segment (show in figure 4:5) is responsible for connecting the Lower Arm Cuff to the assembly, focusing on the lower arm. This component offers structural support, allowing the cuff to be attached to the lower arm area. The device's design seeks to provide a secure and comfortable fit while optimising performance on the lower arm.

Figure 4.5 LowerArmSegment Lower

4.2.2 3D printing

The arm exoskeleton 3D printing model prioritised accuracy and durability. The design's complexities were methodically handled using modern approaches such as parametric design and assembly. The prototyping process began with a critical 3D-printed test component, which provided practical insights into the realisation of our conceptualised concepts. PLA Plus, known for its increased strength, was chosen for printing crucial components because of its longevity. Printer calibration guaranteed excellent print quality and structural integrity. PLA Plus's appropriateness was confirmed by rigorous testing, which assessed aspects such as flexibility and weight. This devotion demonstrates our commitment to developing a robust and user-friendly arm exoskeleton using sophisticated 3D printing processes.

Figure 4.6 Printing Process using 3d printing

4.2.3 Sewing Velcro Tape onto Arm Exoskeleton Cuff

The Velcro tape sewing process onto the arm exoskeleton cuffs involves meticulous steps for optimal functionality. After selecting a high-quality Velcro tape, strategic attachment points on the cuffs are identified and marked for secure fastening. Ensuring alignment and symmetry, the tape is sewn onto the lower and upper cuffs using a durable thread, tailored to the exoskeleton's material strength. Precision is achieved through either a sewing machine or hand-sewing techniques, based on project requirements. This Velcro tape attachment allows users to easily adjust the cuffs, accommodating different arm sizes, enhancing the overall versatility and comfort of the arm exoskeleton.

Figure 4.7 Sewing Velcro Tape onto Arm Exoskeleton Cuff

4.2.4 Assembly Process

Begin the upper arm segment assembly by connecting UpperArmCuffs and UpperArmSegment with long M4x35 mm screws and nuts. With the same screws, secure the MotorAdapter. Prepare the motor by ensuring that its integrated end-stop prevents hyperextension. Calibrate the end-stop using the round black motor adapter and secure it with M2 wood screws. Insert the motor into the MotorAdapter and secure it with M2x30 mm screws. Make sure the elbow joint is straight at the end-stop and moves upward when flexed. Protect the motor and lower arm segments.. Check for smooth elbow joint movement, as well as stability, tight connections, and proper alignment for functional completion. The figure assembly of arm exoskeleton show in figure 4:8.

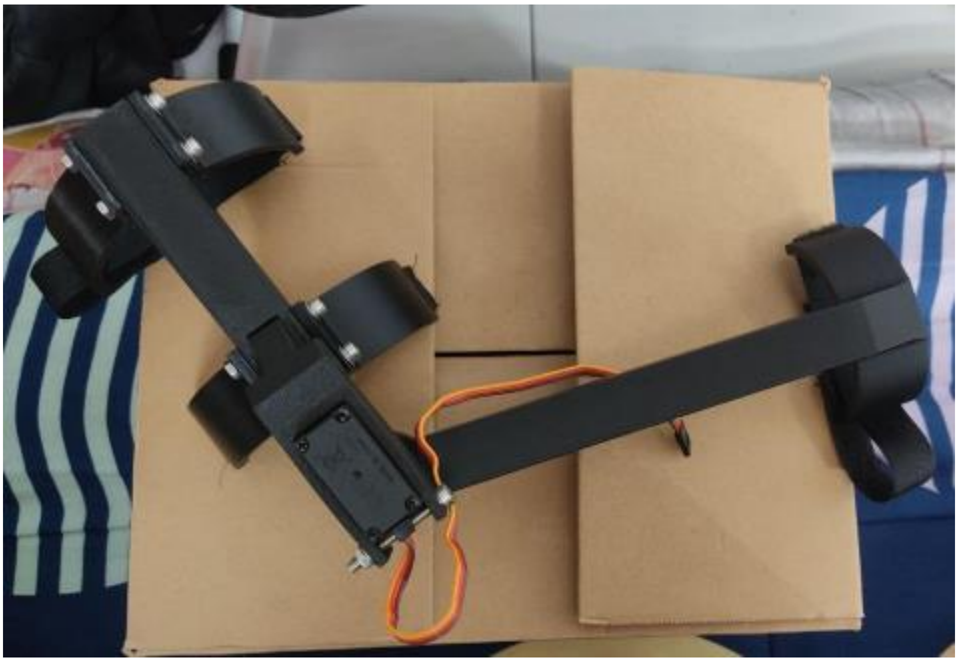

Figure 4.8 Assembled full model arm exoskeleton

After finishing the assembling procedure, the gadget must be carefully placed on the arm and tested for functioning. Insert the arm gently, fasten the cuffs, and articulate the elbow joint (see Figure 4:9). The elbow should move smoothly and with little resistance from the passive motor. This step of testing verifies that the assembled components work properly and are compatible with the arm.

Figure 4.9 Checking for smooth elbow joint movement

4.3 Electronics parts Development

The exoskeleton project employs ion and lithium polymer batteries to power its circuit, with ion batteries specifically fueling the EMG sensor. This sensor detects subtle electrical signals from muscles, providing input to the servo motor for controlled movement. The Arduino UNO, highlighted in a previous chapter, assumes a pivotal role in system control and design. Its integration ensures efficient coordination of the electronics, facilitating seamless communication between the EMG sensor and servo motor. Overall, this combination of components empowers the exoskeleton to interpret muscle signals and execute precise movements, enhancing its functionality and user interface in a compact and energy-efficient manner.

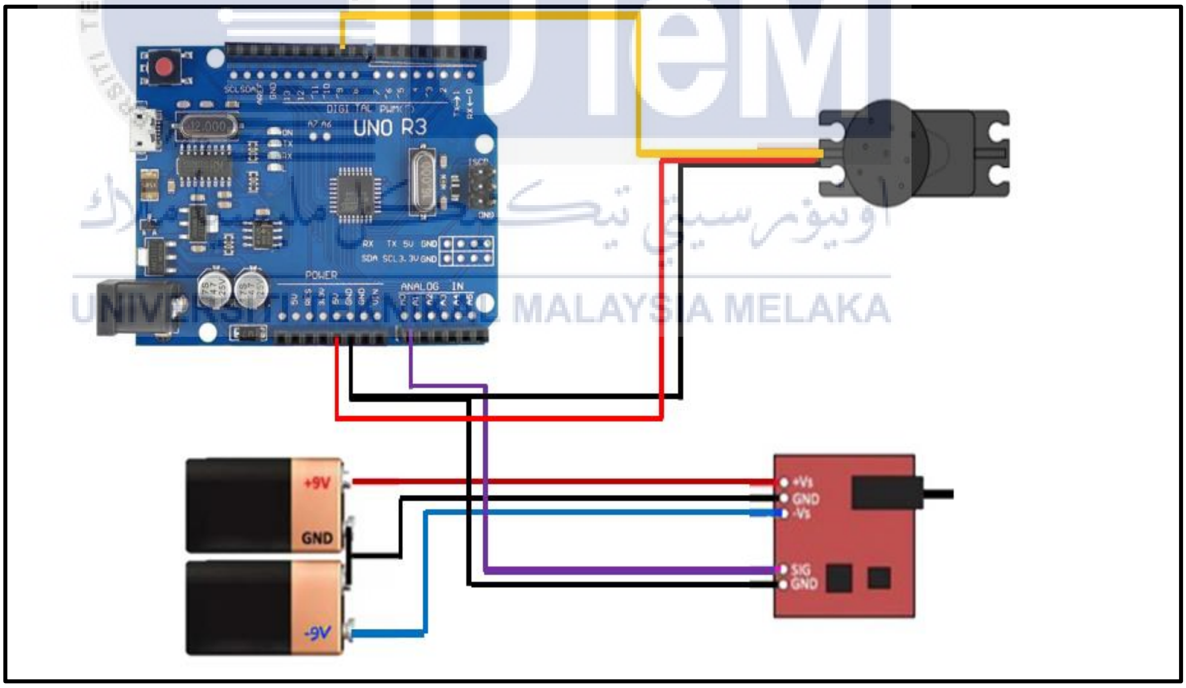

Figure 4.10 Schematic Diagram of Complete Circuit

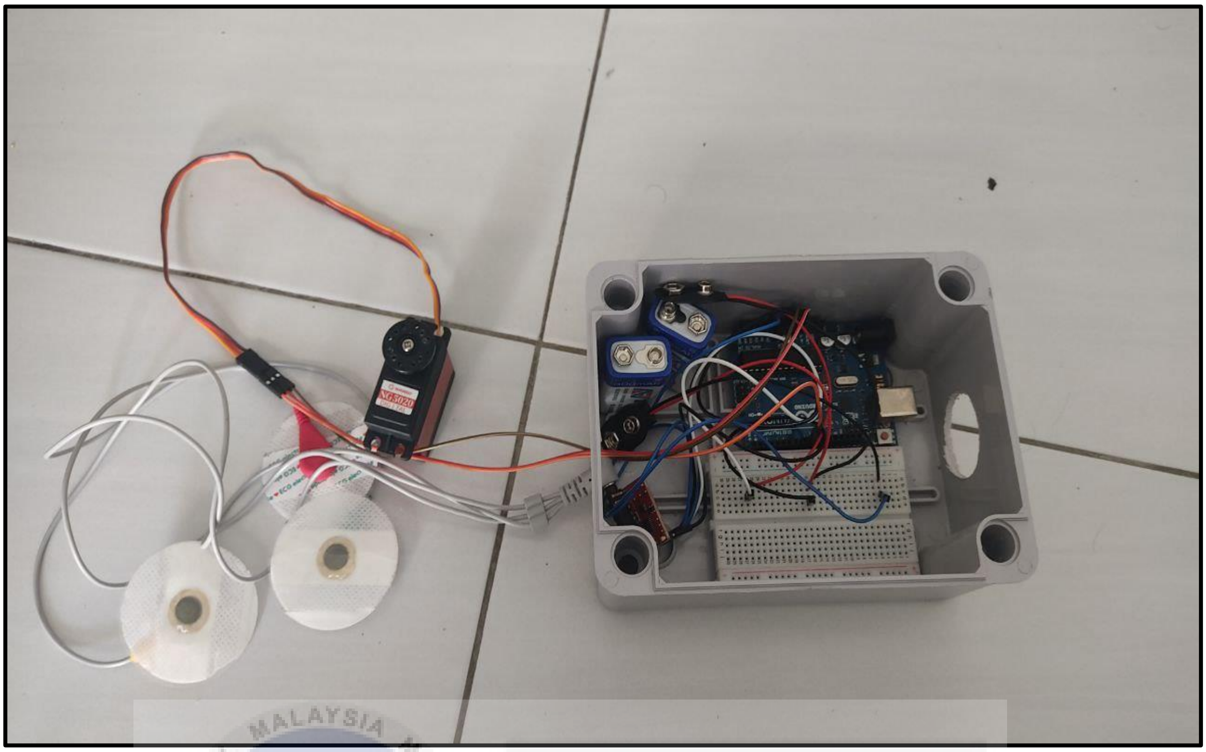

Figure 4.11 Electronics parts development

4.4 Data Results

The diagram depicts the movement of the Exoskeleton before and after lifting items. The motor adjusts its angle in response to inputs from the signal from EMG sensor. The exoskeleton system is activated when signals from the EMG sensor are detected. To confirm the project's goal of making heavy item lifting easier, five people carried 2.5kg and 5.0kg weights for 10 seconds each. The EMG sensor output represents the electrical impulses created by the muscle, with higher signals indicating more energy generation. This data collecting technique evaluates the performance of the exoskeleton, offering information regarding its usefulness in assisting load jobs.

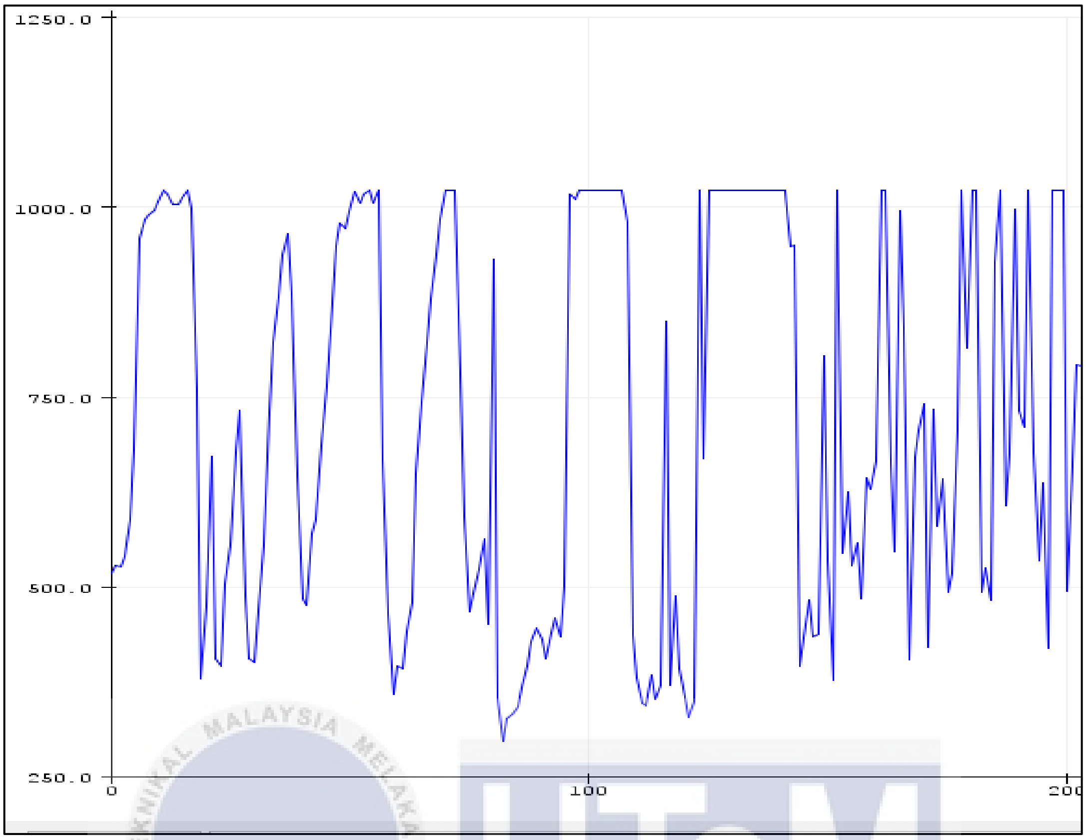

Figure 4.12 Serial Plotter reading load before using Exoskeleton

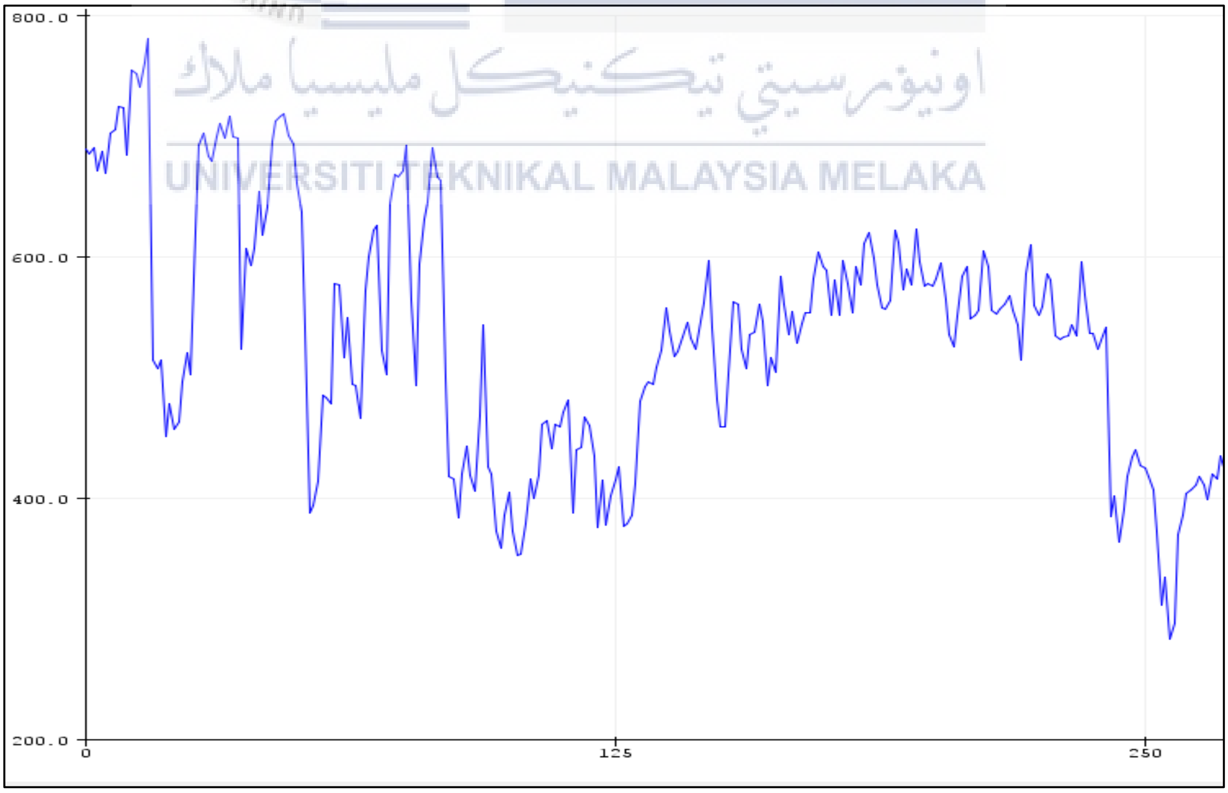

Figure 4.13 Serial Plotter reading load after using Exoskeleton

In the evaluation of the performance of the exoskeleton system, Haziq, Azfar, Sofian, Azim, and Iqmal all shown consistent efficacy. Despite individual differences, the steady drop in data output demonstrates the exoskeleton's usefulness in handling large things, which aligns with project objectives. The table summarises important information such as their gender, weekly exercise frequency, and arm injury history, providing insight into their physical activity habits and arm-related factors.

Table 4:1 Information of the participant

No	Name	Gender	Frequency of exercise per week	History of arm injuries
1	Haziq	Male	1-3 days	No
2	Azfar	Male	5-7 days	No
3	Sofian	Male	6-7 days	No
4	Azim	Male	5-7 days	No
5	Iqmal	Male	1-2 days	Yes

This compelling evidence highlights the system's concrete influence in enhancing human strength, showcasing its potential applicability in tasks requiring the lifting or carrying of substantial loads. Table 4.1 show the first attemt of the Exoskeleton system performance with the 5 different peopl. This consistent effectiveness spans participants with diverse backgrounds.

Table 4:2 System performance for the first attempt

No	Name	Gender	Average reading lift 2.5 kg in 10 second without using Exoskeleton(milivolt)	Average reading lift 2.5 kg in 10 second using Exoskeleton(milivolt)	Percentage of decreasing (%)
1	Haziq	Male	853.27	507.65	40.50
2	Azfar	Male	651.91	416.79	36.06
3	Sofian	Male	743.97	398.72	50.44
4	Azim	Male	645.41	402.50	37.64
5	Iqmal	Male	856.35	477.25	44.26

Graph shown first attemt exoskeleton impact on participants' EMG readings during 2.5 kg lifting, showing individual variations.

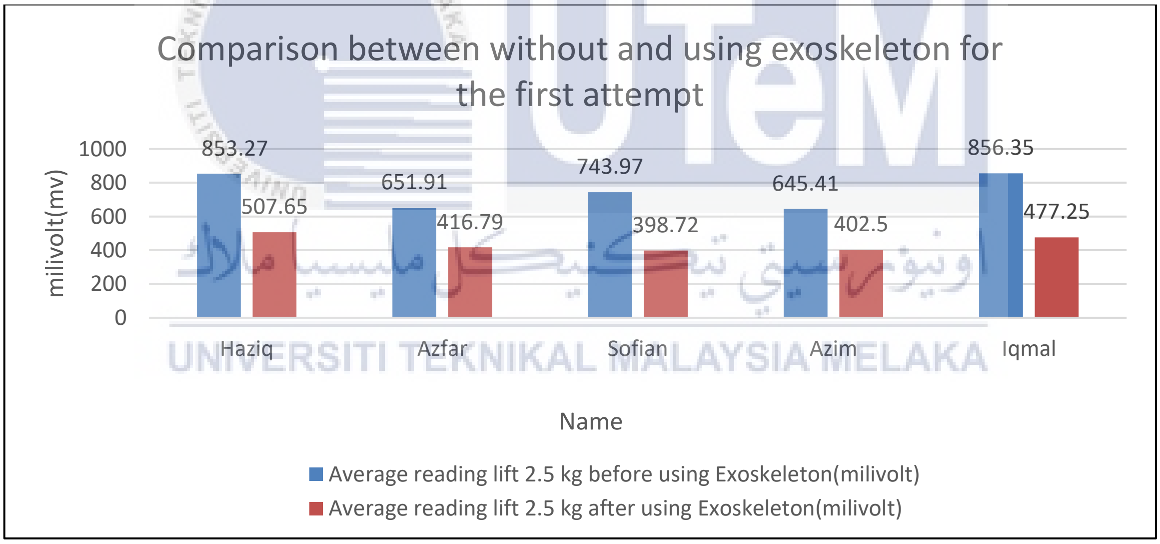

Figure 4.14 Comparison between without and using exoskeleton for the first attempt

The results show a consistent trend among individuals, demonstrating a noticeable fall in performance indicators after interfacing with the Exoskeleton system after engaging in active physical activities. Haziq, Azfar, Sofian, Azim, and Iqmal all saw reductions in their respective performance characteristics ranging from 36.06% to 50.44%. This demonstrates the impact of the exoskeleton on muscle activation during and after exertion, implying a possible influence on users' physical endurance and efficiency. The variable degrees of performance degradation underscore the significance of tailoring the exoskeleton to different user profiles and activities. Additional investigation and fine-tuning of the exoskeleton's design and functionality may be required to maximise its effectiveness and accommodate to users' specific physiological responses..

The results of the second attempt to evaluate the performance of the Exoskeleton system are shown in Table 4.2. After all users engaged in active activities requiring loads, before the data was collected. This consistent effectiveness is demonstrated across participants from various backgrounds, suggesting the system's ability to reliably improve performance after physical activity participation, highlighting its potential benefits across diverse user profiles.

Table 4:3 System performance for the second attempt

No	Name	Gender	Average reading lift 2.5 kg in 10 second without using Exoskeleton(milivolt)	Average reading lift 2.5 kg in 10 second using Exoskeleton(milivolt)	Percentage of decreasing (%)
1	Haziq	Male	948.23	800.09	15.62
2	Azfar	Male	723.76	650.32	10.14
3	Sofian	Male	778.98	591.82	23.25
4	Azim	Male	689.87	558.90	19.89
5	Iqmal	Male	889.04	765.98	13.84

Graph shown second attemt exoskeleton impact on participants' EMG readings during 2.5 kg lifting, showing individual variations

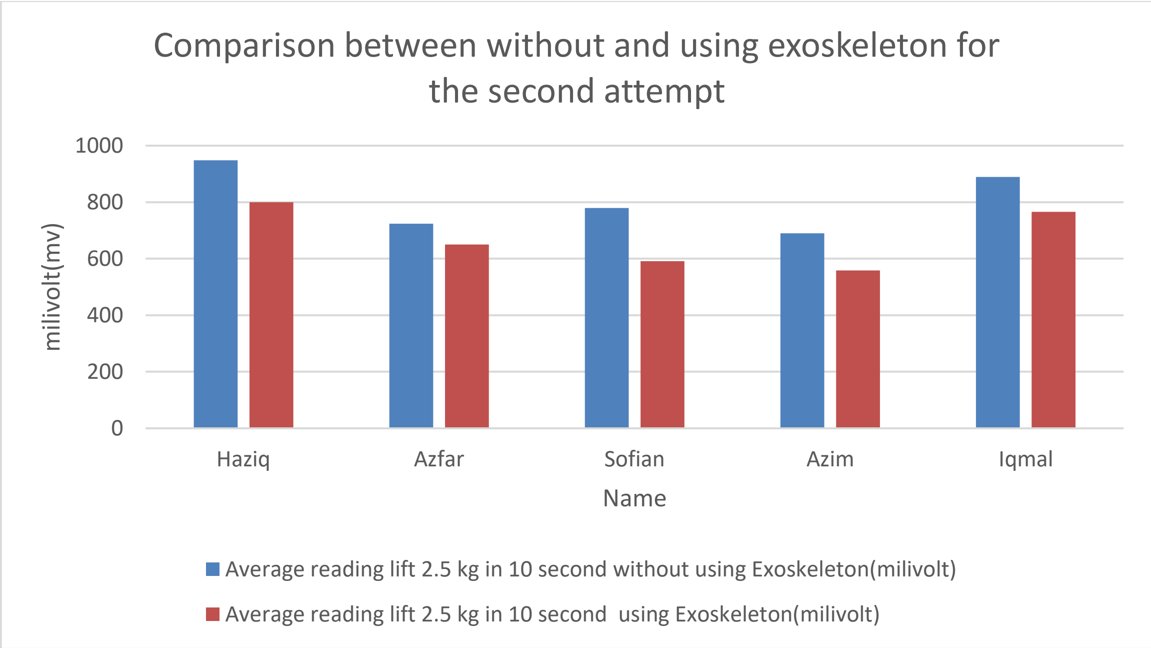

Figure 4.15 Comparison between without and using exoskeleton for the second attempt

The result compares the performance parameters of individuals during a 2.5 kg lift lasting 10 seconds after all users engaged in active activities requiring loads, before the data was collected., with trials conducted without and with the Exoskeleton. In the absence of the Exoskeleton, Haziq, Azfar, Sofian, Azim, and Iqmal had average readings of 948.23, 723.76, 778.98, 689.87, and 889.04 millivolts, respectively. Their readings changed after integrating the Exoskeleton to 800.09, 650.32, 591.82, 558.90, and 765.98 millivolts, respectively. The resulting performance losses vary from 10.14% to 23.25%. This research reveals that the Exoskeleton has variable effects on lifting activities, demonstrating potential usefulness but also emphasising the necessity for nuanced changes to optimise individual outcomes. From this result, arm exoskeleton can reduce muscle reading while the user in active mode user their arm for the activity

The results of the third study of the Exoskeleton system's performance, specifically with a load increase from 2.5kg to 5.0kg, are summarised in Table 4.3. This investigation provides a thorough evaluation of how the system reacts to high-stress settings, offering light on its operational capabilities. The results not only highlight the system's performance under severe loads, but they also provide useful insights that may be used to make prospective improvements to further optimise its operation. This information leads to a better knowledge of the resilience of the Exoskeleton system and informs prospective refinement and improvement possibilities in its overall design and functioning.

Table 4:4 System performance for the third attempt

No	Name	Gender	Average reading lift 5.0 kg in 10 second without using Exoskeleton(milivolt)	Average reading lift 5.0 kg in 10 second using Exoskeleton(milivolt)	Percentage of decreasing (%)
1	Haziq	Male	738.99	574.21	21.98
2	Azfar	Male	674.32	413.21	25.52
3	Sofian	Male	669.00	491.43	26.63
4	Azim	Male	597.56	453.21	24.16
5	Iqmal	Male	701.71	521.09	25.73

Graph shown second attemt exoskeleton impact on participants' EMG readings during 5.0 kg lifting, showing individual variations

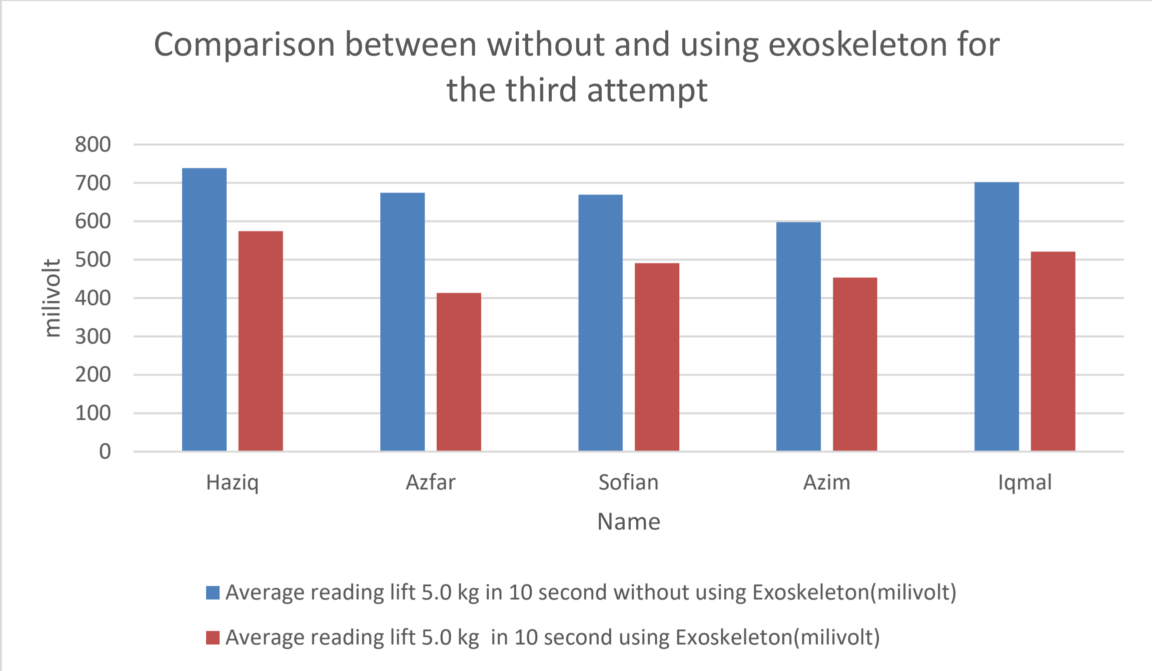

Figure 4.16 Comparison between without and using exoskeleton for the third attempt

The result compares individuals' performance in lifting a 5.0 kg burden for 10 seconds without and with the help of an Exoskeleton, measured in millivolts (mV). The "Percentage of Decrease" column shows the reduction in electrical readings when the Exoskeleton is used, demonstrating its efficiency in reducing the participants' physical effort. Haziq, Azfar, Sofian, Azim, and Iqmal show percentage drops of 21.98%, 25.52%, 26.63%, 24.16%, and 25.73%, indicating varied degrees of help and the potential for enhanced efficiency with the Exoskeleton.

The results of the fourth iteration evaluating the Exoskeleton system's performance in lifting a 5kg load are detailed in Table 4:4. Importantly, prior to data collection, all participants engaged in dynamic activities requiring physical exertion. This deliberate approach was taken to simulate real-world scenarios and test the system under conditions resembling active engagement. The findings highlight the Exoskeleton system's consistent and noticeable effectiveness, demonstrating its ability to consistently improve performance following a variety of physical activities..

Table 4:5 System performance for the third attempt

No	Name	Gender	Average reading lift 5.0 kg in 10 second without using Exoskeleton(milivolt)	Average reading lift 5.0 kg in 10 second using Exoskeleton(milivolt)	Percentage of decreasing (%)
1	Haziq	Male	856.73	663.75	22.52
2	Azfar	Male	724.08	598.64	17.32
3	Sofian	Male	750.37	601.06	19.89
4	Azim	Male	767.79	656.87	14.44
5	Iqmal	Male	956.25	786.79	17.72

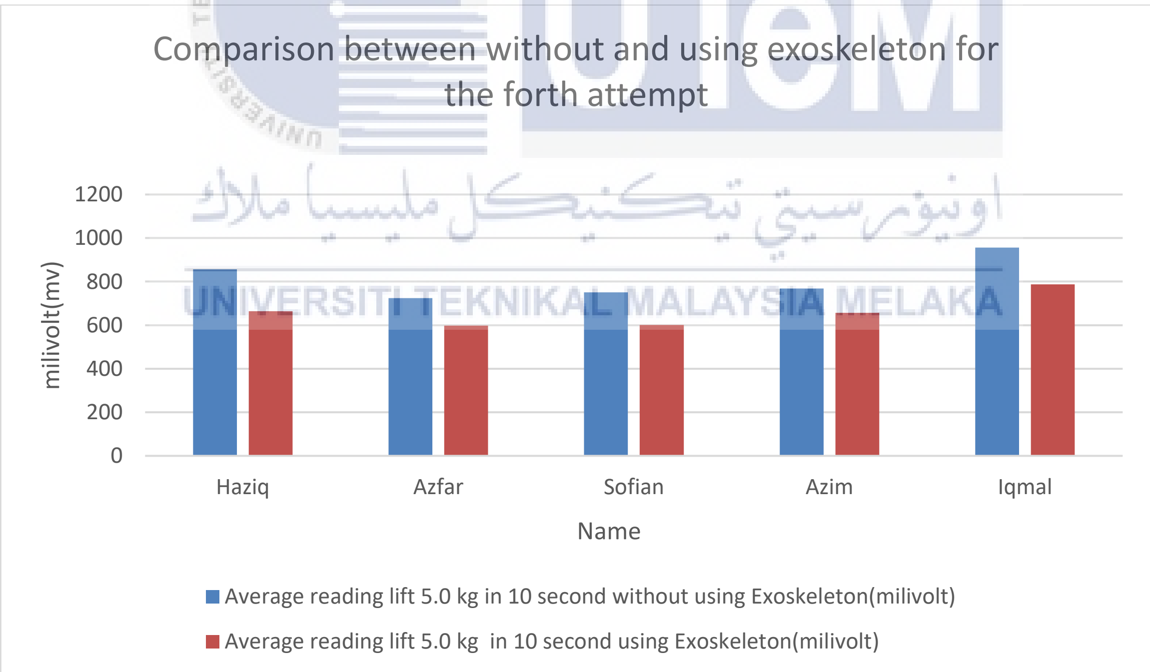

Figure 4.17 Comparison between without and using exoskeleton for the third attempt

The outcome summarises the results of the Exoskeleton system's performance evaluation during a 5.0 kg lifting task for 10 seconds, displaying individual data for participants Haziq, Azfar, Sofian, Azim, and Iqmal. The "Average Reading Lift" columns show the electrical signal measurements without and with the Exoskeleton, while the "Percentage of Decrease" column shows the reading reduction when using the Exoskeleton. Notably, the system consistently demonstrated effectiveness, with participants experiencing varying degrees of percentage reduction ranging from 14.44% to 22.52%. This demonstrates the Exoskeleton's ability to augment lifting capabilities in a wide range of individuals, emphasising its potential to improve overall performance during load-bearing activities.

4.5 Summary

In summary, the experiment was a success, proving the usefulness of the built Exoskeleton in assisting people with heavy item lifting. The data acquired from system performance substantiates the proof that the Exoskeleton does, in fact, make numerous persons more comfortable, regardless of their unique backgrounds and genders. Finally, the findings reveal that the system performs in line with the desired goals, demonstrating its effective performance. The Exoskeleton not only serves its goal efficiently, but it also proves adaptive to users of varied characteristics, demonstrating its usefulness and effectiveness in supporting persons in the work of lifting large things.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In conclusion, the project achieved its objectives by designing and building a surface electromyography (EMG) sensor-based exoskeleton arm for a Powered Smart Mobility (PSM) system. The created robotic arm interprets muscle impulses recorded by EMG sensors on the skin, opening up new possibilities for those with motor disabilities. This technology advancement has the potential to significantly improve such people's daily lives by giving them greater mobility and autonomy. Experiments with persons lifting 2.5 kg and 5.0 kg loads were used to evaluate the efficacy of the constructed exoskeleton arm. When compared to a supporting system, the exoskeleton arm produced less muscle force. During the use of the exoskeleton for a 2.5 kg lift, performance deterioration ranged from 36.06% to 50.44%, highlighting its influence on post-physical activity muscle activation and efficiency. A nuanced influence, as seen by a 10.14% to 23.25% drop during a 5.0 kg lift, highlights the importance of personalised adaptations. Notably, the exoskeleton arm, particularly in assisting weightlifting exercises, demonstrates its practical value, as demonstrated by thorough testing. The project's overall performance represents a significant step forward in the field of assistive robotics, leading to an enhanced quality of life and increased functioning for users with motor problems.

5.2 Future Work

A smartphone application might be developed in the future to improve the Exoskeleton project. This software would visually display muscle data gathered during particular actions and show how much force the muscle conserved throughout these activities. In comparison to the present dependency on Arduino IDE software, this user-friendly interface promises to improve practicality by offering real-time insights and usability. Exploration of gesture recognition skills for intuitive control might also be explored as future work for the arm exoskeleton.

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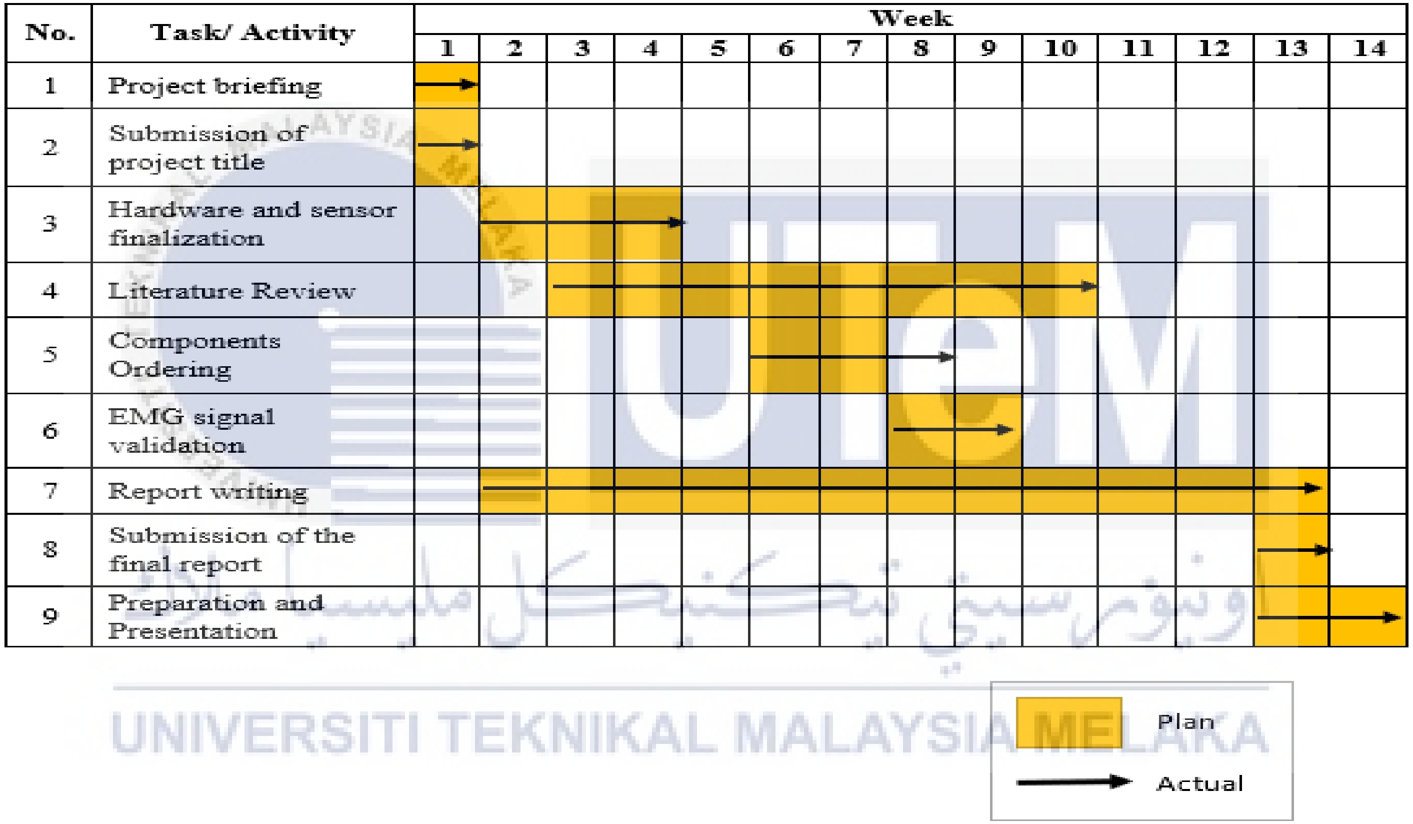
APPENDICES

PROJECT CODDING

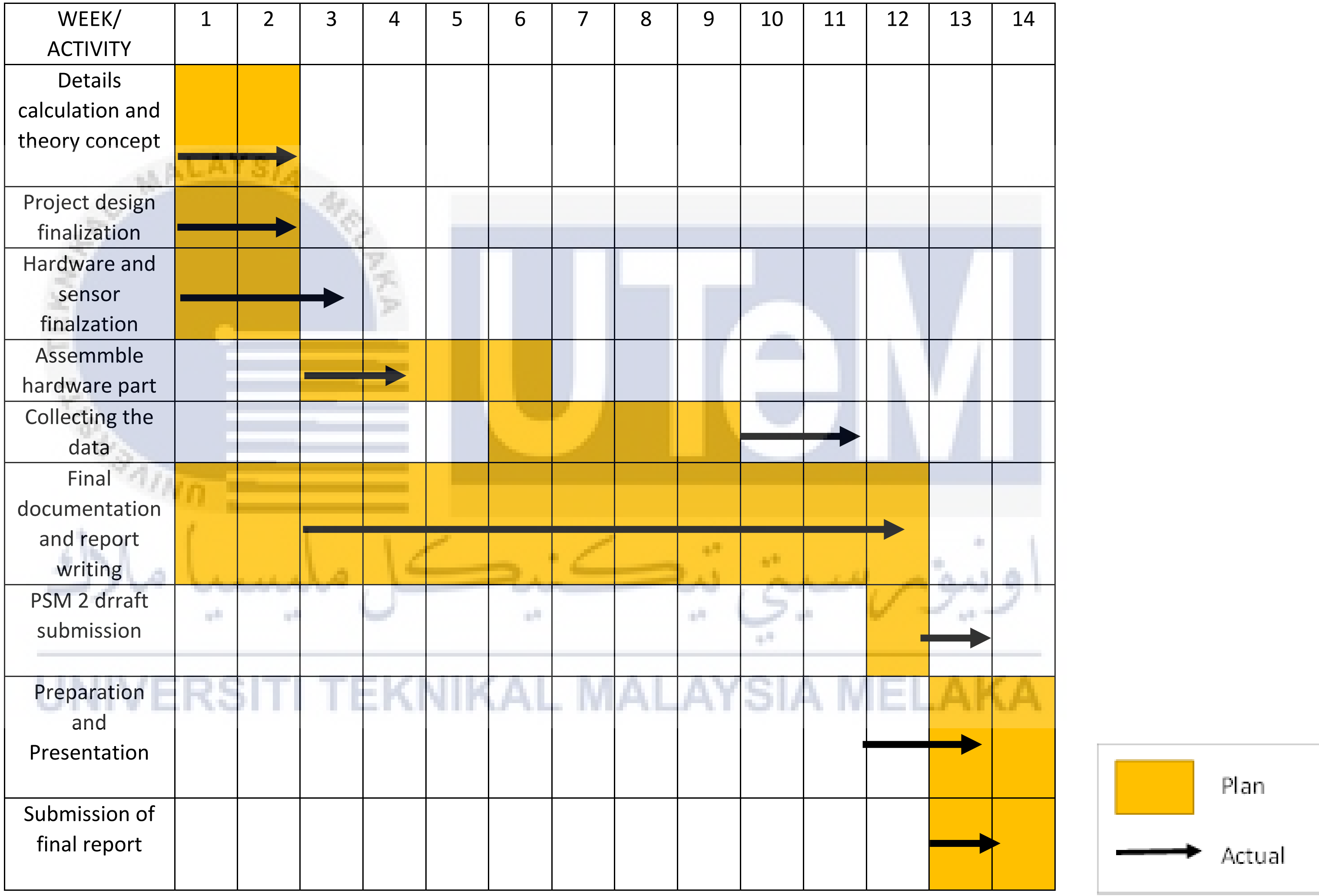
```
#include <Servo.h>

const int emgPin = A0; // Analog pin for EMG sensor
const int servoPin = 9; // Pin for servo motor

Servo myServo;

void setup() {
  Serial.begin(9600);
  myServo.attach(servoPin);

  // Set the initial position of the servo to 0 degrees
  myServo.write(165);
}

void loop() {
  delay(1000); // Adjust the delay based on your preference

  Serial.println("Waiting for EMG signal...");

  // Wait for EMG signal
  while (analogRead(emgPin) < 1023) {
    delay(1000);
    Serial.println("EMG signal detected!");
    moveServo();
  }
}

void moveServo() {
```

```
  myServo.write(110); // Move to position 135 degrees

  // Display EMG values during the activity
  Serial.println("EMG values during activity:");
  unsigned long activityStartTime = millis();
  while (millis() - activityStartTime < 10000) {
    int emgValue = analogRead(emgPin);
    Serial.println(emgValue);
    delay(100);
  }

  myServo.write(145); // Move back to the default position (165 degrees)
  Serial.println("Servo back to position 165");

  // Wait for 5 seconds before checking for EMG signal again
  delay(5000);
}
```

PSM 1 Gantt chart



PSM 2 Gantt chart



PSM 2 Gantt chart